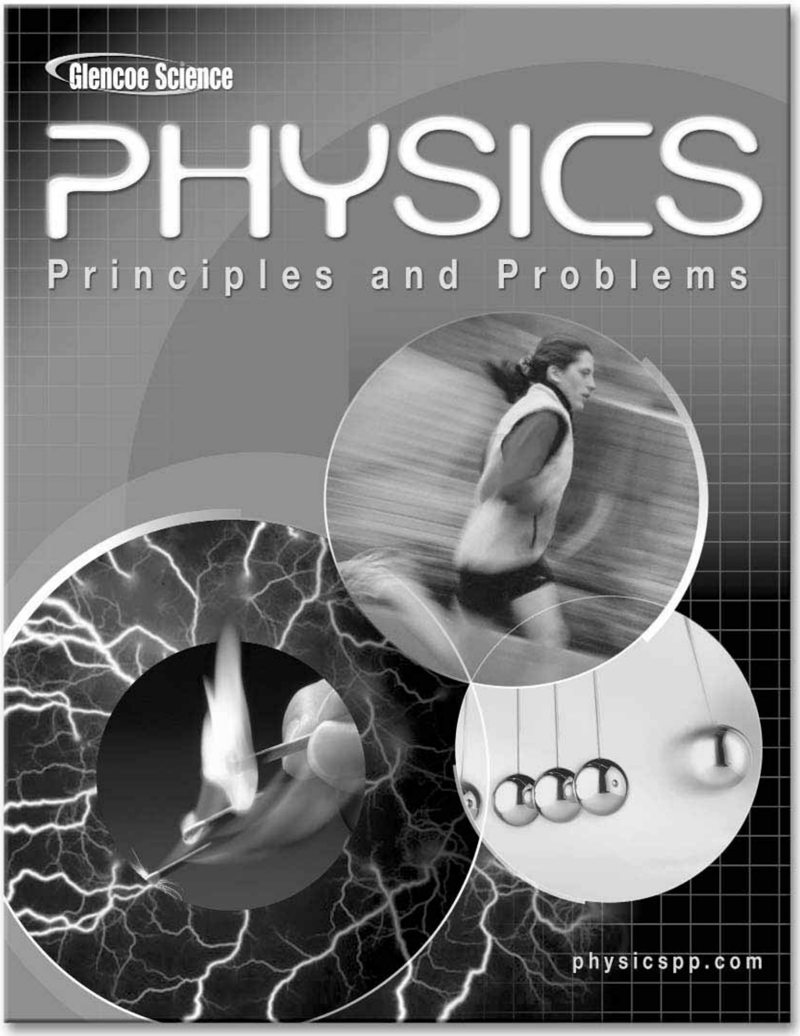

Chapters 16–20 Resources

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A Glencoe Program

PHYSICS
Principles and Problems

Student Edition

Teacher Wraparound Edition

Teacher Chapter Resources
- Mini Lab Worksheets
- Physics Lab Worksheets
- Study Guide
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Contents

Chapters 16–20 Resources

To the Teacher

This book contains resources that support five Student Edition chapters of ***Physics: Principles and Problems.*** The worksheets and activities have been developed to help you teach these chapters more effectively. You will find in chapter order:

Reproducible Pages

Hands-on Activities

Mini Lab and Physics Lab Worksheets: These worksheets are expanded versions of the Mini Labs and Physics Labs that appear in the five Student Edition chapters supported in this book. All materials lists, procedures, and questions are repeated so that students can complete a lab in most cases without having a textbook on the lab table. Data tables are enlarged so they can be used to easily record data, and all lab questions are reprinted with lines on which students can write their answers. For student safety, all appropriate safety symbols and caution statements have been reproduced on these pages. Answer pages for each Mini Lab and Physics Lab Worksheet are included in the Teacher Guide and Answers section at the back of this book.

Extension and Intervention

Study Guide: These pages help your students learn physics vocabulary and concepts. Study Guide worksheets typically consist of six pages of questions and exercises for each of the five Student Edition chapters supported in this book. Items are presented in a variety of objective formats: matching, true/false, interpreting diagrams and data, multiple choice, short-answer questions, and so on. The first Study Guide worksheet for each chapter reviews vocabulary. Subsequent worksheets closely follow the organization of the textbook, providing review items for each textbook section and references to specific content.

Students will find the Study Guide worksheets helpful for previewing or reviewing chapter material. As a preview, the worksheets help students focus on the concepts at the time you assign the reading. Students can complete each Study Guide section after reading the corresponding textbook section. Some students will have more success completing the sheets in smaller chunks. For this reason, the question sets on the Study Guide pages are referenced to specific readings in the textbook. When complete, these worksheets will prove to be an excellent review instrument. Answers to the Study Guide pages are included in the Teacher Guide and Answers section at the back of this book.

Reinforcement: These pages provide opportunities that complete your teaching cycle and benefit all your students. Reinforcement masters are especially helpful for students who require additional instruction in order to understand certain concepts. A Reinforcement master is provided for each of the five Student Edition chapters supported in this book. Answers to these pages are included in the Teacher Guide and Answers section at the back of this book.

Enrichment: These activities offer students the chance to apply physics concepts to new situations. Students explore high-interest topics in a variety of formats. Some of the masters are hands-on activities. An Enrichment master is provided for each of the five Student Edition chapters supported in this book. Answers to these pages are included in the Teacher Guide and Answers section at the back of this book.

Transparency Activities

Teaching Transparency Masters and Activities: These transparencies relate to major concepts that will benefit from an extra visual learning aid. Most of the transparencies contain art or photos that extend the concepts put forth by those in the textbook. Others contain art or photos directly from the Student Edition. There are 120 Teaching Transparencies. The ones that support these five Student Edition chapters are provided here as black-and-white masters accompanied by worksheets that review the concepts presented in the transparencies. Teaching Tips for some transparencies and answers to all worksheet questions are provided in the Teacher Guide and Answers section at the back of this book.

Assessment

Section Quiz: The Section Quiz page consists of questions or problems that focus on key content from one section of the Student Edition. Each quiz typically includes conceptual items that require a written response or explanation and items that require problem-solving skills or mathematical calculations, where applicable. The Section Quiz offers representative practice items that allow you to monitor your students' understanding of the textbook. Answers to each Section Quiz are provided in the Teacher Guide and Answers section at the back of this book.

Chapter Assessment: The Chapter Assessment pages provide materials to evaluate your students' understanding of concepts and content from the five Student Edition chapters supported in this book. Each test consists of six pages of material, which is divided into three sections.

- Understanding Physics Concepts requires students to demonstrate their knowledge of vocabulary and other basic information presented in the chapter. They are assessed through a variety of question types, including matching, modified true/false, short answer/fill-in, and multiple choice.
- Thinking Critically requires students to use higher-order learning skills. Students will need to interpret data and discover relationships presented in graphs and tables. Other questions may require them to apply their understanding of concepts to solve problems, compare or contrast situations, and make inferences or predictions.
- Applying Physics Knowledge consists of items that assess students' ability to extend their learning to new situations. Assessment is done qualitatively through short-answer questions, and quantitatively through problems. The questions and problems in this section are more difficult than those presented earlier and generally require more calculations as well as a deeper comprehension of chapter concepts.

Teacher Guide and Answers

Answers or possible answers to all worksheet questions and activities can be found in order of appearance at the back of this book. Criteria for acceptable answers are found where appropriate.

CHAPTER
16 Reproducible Pages Contents

Light

Date ________________ Period ________________ Name ______________________________

CHAPTER 16

Mini Lab Worksheet

Color by Temperature

Some artists refer to red and orange as hot colors and green and blue as cool colors. Do colors really relate to temperature in this way?

1. Obtain a glass prism from your teacher.
2. Obtain a lamp with a dimmer switch from your teacher. Turn on the lamp and turn off the room light. Set the dimmer to minimum brightness of the lamp.
3. Slowly increase the brightness of the lamp. ***CAUTION: Lamp can get hot and burn skin.***
4. **Observe** the color of light produced by the prism and how it relates to the warmth of the lightbulb on your hand.

Analyze and Conclude

5. What colors appeared first when the light was dim?

____

6. What colors were the last to appear as you brightened the light?

____

7. How do these colors relate to the temperature of the filament?

____

____

Date ____________ Period ____________ Name ____________________

CHAPTER 16

Physics Lab Worksheet

Materials

- **Minimize the length of time you look directly at bright light sources.**
- **Do not do this lab with laser light sources.**
- **Do not look at the Sun, even if you are using polarizing filters.**
- **Light sources can get hot and burn skin.**

- two polarizing filter sheets
- incandescent light source
- fluorescent light source
- pieces of white and black paper
- calculator with a liquid crystal display
- clear plastic protractor

Polarization of Light

A light source that produces transverse light waves that are all in the same fixed plane is said to be polarized in that plane. A polarizing filter can be used to find light sources that produce polarized light. Some media can polarize light as it transmits through the filter. Such media are said to be optically active. In this activity, you will investigate these concepts of polarized light.

Question

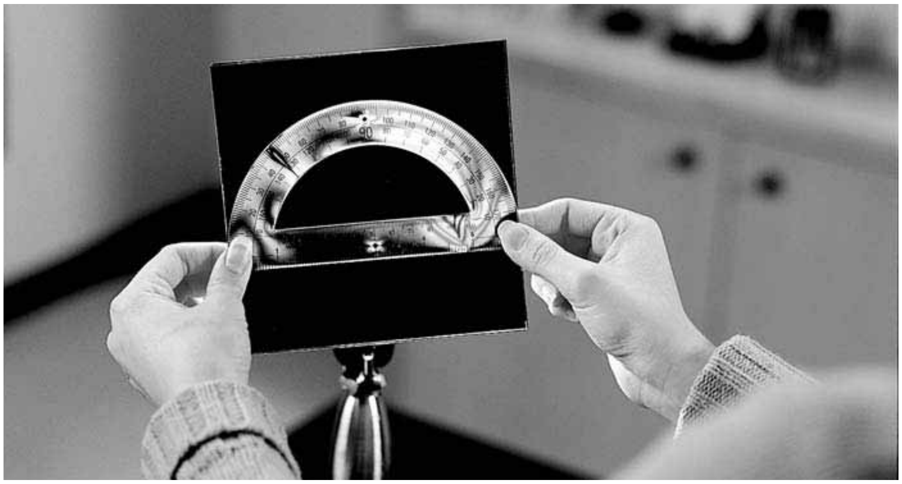
What types of luminous and illuminated light sources produce polarized light?

Objectives

- **Experiment** with various sources of light and polarizing filters.
- **Describe** the results of your experiment.
- **Recognize** possible uses of polarizing filters in everyday life.

Procedure

1. Take a polarizing filter and look at an incandescent light source. Rotate the filter. Write your observations in the data table.
2. Use a polarizing filter to look at a fluorescent light source. Rotate the filter. Write your observations in the data table.
3. Use a polarizing filter to observe light reflected off of a mirror surface. Rotate the filter. Record your observations in the data table.



Data Table	
Light Source	**Observations**
1	
2	
3	
4	
5	
6	
7	
8	

4. Use a polarizing filter to observe light reflected off of a white piece of paper. Rotate the filter. Record your observations in the data table.

5. Use a polarizing filter to observe light reflected off of a piece of black paper. Rotate the filter. Record your observations in the data table.

6. Use a polarizing filter to observe a liquid crystal display on a calculator. Rotate the filter. Write your observations in the data table.

7. Place one polarizing filter on top of the other filter. Look at an incandescent light source through this set of the filters. Rotate one of the filters with respect to the other. Make a complete rotation. Record your observations in the data table.

8. Place a clear, plastic protractor between the two polarizing filters. Look at an incandescent light source with this. Do a complete rotation of one of the filters. Position the two filters the same way that produced no light in step 7. Record your observations in the data table.

Analyze

1. **Interpret Data** Does incandescent light produce polarized light? How do you know?

2. **Interpret Data** Does fluorescent light produce polarized light? How do you know?

3. **Interpret Data** Does reflected light from a mirror surface produce polarized light? How do you know?

4. **Compare and Contrast** How does reflected light from white paper compare to reflected light from black paper in terms of polarized light? Why are they different?

5. **Interpret Data** Do liquid crystal displays produce polarized light? How do you know?

Conclude and Apply

1. **Analyze and Conclude** How can two polarizing filters be used to prevent any light from passing through them?

2. **Analyze and Conclude** Why can the clear, plastic protractor between the polarizing filters be seen even though nothing else can be seen through the polarizing filters?

3. **Draw Conclusions** In general, what types of situations produce polarized light?

Going Further

1. On a sunny day, look at the polarization of blue sky near and far from the Sun using a polarizing filter. ***CAUTION: do not look directly at the Sun.*** What characteristics of polarized light do you observe?

2. Is reflected light from clouds polarized? Make an observation to confirm your answer.

Real-World Physics

1. Why are high-quality sunglasses made with polarizing lenses?

2. Why are polarizing sunglasses a better option than tinted sunglasses when driving a car?

Physics Online

To find out more about light, visit the Web site:
physicspp.com

Date ____________ Period ____________ Name ____________

CHAPTER

16 Study Guide

Light

Vocabulary Review

Write the term that correctly completes the statement. Use each term once.

observed light frequency	**luminous intensity**	**primary pigment**
Doppler shift	**luminous source**	**ray model of light**
complementary color	**Malus's law**	**secondary color**
illuminance	**opaque**	**secondary pigment**
illuminated source	**polarized**	**translucent**
luminous flux	**primary color**	**transparent**

1. ____________ The illumination of a surface is the _____.

2. ____________ The _____ of a given color forms white light when it combines with that color.

3. ____________ The _____ of a point source is the luminous flux that falls on 1 m^2 of a sphere with a 1-m radius.

4. ____________ A measure of the total rate at which light is emitted from a source is the _____.

5. ____________ Light that vibrates in a single plane is _____.

6. ____________ A color formed from two primary colors of light is a(n) _____.

7. ____________ An object that emits light is a(n) _____.

8. ____________ The _____ uses straight lines to describe how light interacts with matter.

9. ____________ A material that transmits light clearly is _____.

10. ____________ A(n) _____ becomes visible when light reflects off it.

11. ____________ Red is a(n) _____; it forms white light when mixed with green and blue light.

12. ____________ A(n) _____ absorbs only one primary color from white light.

13. ____________ A(n) _____ absorbs two primary colors of light.

14. ____________ A _____ material transmits light, but objects can't be seen clearly through it.

15. ____________ A material that transmits no incident light is a(n) _____ material.

16. ______________________ _____ explains the reduction of light intensity as it passes through a polarizing filter.

17. ______________________ The term _____ describes the number of light wave oscillations an observer sees.

18. ______________________ Astronomical observers use the _____ to determine whether Earth is moving closer to or farther away from a star.

Section 16.1 Illumination

In your textbook, read about the ray model of light on pages 432–434.

For each statement below, write* true *or rewrite the italicized part to make the statement true.

1. ______________________ *The Sun* is Earth's major source of light.

2. ______________________ Light bulbs and LEDs are *illuminated* light sources.

3. ______________________ According to *the ray model of light*, light travels in a straight line until reflected or refracted.

4. ______________________ Window glass is *an opaque* medium.

Circle the letter of the choice that best completes the statement or answers the question.

5. _____ is a translucent medium.

a. Steel
b. Aquarium glass
c. Stained glass
d. Rubber

6. Which of the following would not change the path of light?

a. the vacuum of space
b. a mirror
c. a glass of water
d. a raindrop

7. The fact that sharp shadows are cast by the Sun is an indication that light _____.

a. is a wave
b. travels in straight lines
c. is made up of colors
d. travels in a curved path

8. A straight line that represents the path of travel of light is _____.

a. the normal
b. a complement
c. a ray
d. a wave

9. Seventeenth-century Danish astronomer Ole Roemer studied the orbital period of _____ to determine the speed of light.

a. Io
b. Saturn
c. Jupiter
d. Earth's moon

10. How long does light take to cross Earth's orbit?

a. 2 s

b. 8 min

c. 16.5 min

d. 22 min

11. Which choice best describes an inverse-square relationship?

a. Daylight on Mars is dimmer than daylight on Earth.

b. A camera flashbulb produces a sudden burst of light.

c. When you blow out a candle, the room darkens.

d. Installing compact fluorescent bulbs reduces your electric bill.

In your textbook, read about quantity of light on page 433.
Complete questions 12–17 in the table below.

Quantity	Name of Unit	Symbol for Unit
illuminance	**12.**	**13.**
luminous flux	**14.**	**15.**
luminous intensity	**16.**	**17.**

Write the term that correctly completes the statement.

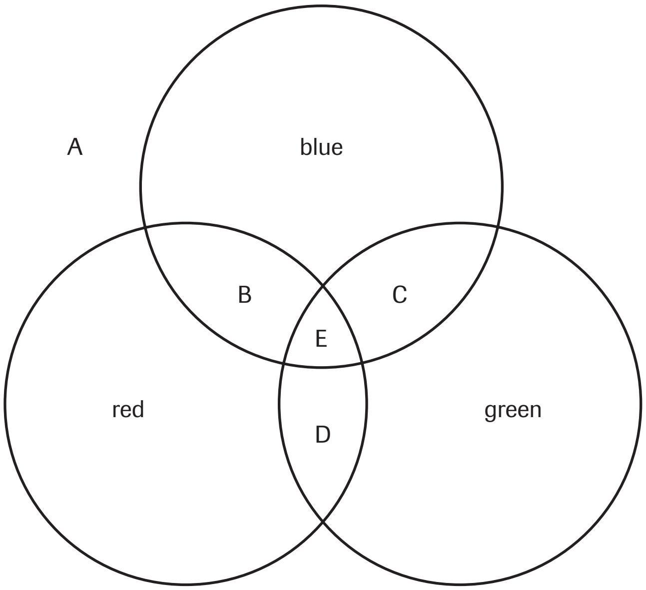
A body that **18.** ______________ light waves is luminous, and a body that simply **19.** ______________ light waves given off by a source is illuminated. A(n) **20.** ______________ object emits light as a result of its high temperature. The official SI unit with which light intensity is calculated is the **21.** ______________. Luminous flux expresses the **22.** ______________ at which light is given off. The term illuminance describes the **23.** ______________ of a surface. If the distance from a surface to a point source of light is doubled, the illumination reaching the surface is only **24.** ______________ as great. The relationship between illuminance and luminous flux is given by the equation **25.** ______________, where the distance to the surface is represented by the variable **26.** ______________. This equation is valid only if the light from the source is striking **27.** ______________ to the surface. It is also valid only for sources small enough or far away enough to be **28.** ______________ sources.

In your textbook, read about light sources and quantities on pages 432–433.
For each description on the left, write the letter of the matching item.

______	**29.** symbol for the speed of light	**a.**	1 lm/m^2
______	**30.** area of the surface of a sphere	**b.**	$\frac{1}{r^2}$
______	**31.** variable for luminous flux	**c.**	$4\pi r^2$
______	**32.** variable for illuminance	**d.**	c
______	**33.** equivalent to the speed of light	**e.**	E
______	**34.** equivalent to 1 lx	**f.**	λf
______	**35.** proportional to illumination	**g.**	P
______	**36.** equivalent to luminous intensity	**h.**	$\frac{P}{4\pi}$

Section 16.2 The Wave Nature of Light

In your textbook, read about the additive color by addition of light on pages 440–442 .
The diagram below represents three overlapping circles of equally intense light of different pure colors. Assume that the circles are projected onto a white screen in an otherwise completely dark room.



Refer to the diagram to answer questions 1–11.

1. ______________________ Why would region A be black?

2. ______________________ What color would region B be?

3. ______________________ What color would region C be?

4. ______________________ What color would region D be?

5. ______________________ What color would region E be?

6. ______________________ Are red, blue, and green light primary or secondary colors?

7. ______________________ Is the light in region C best described as a primary or secondary color?

8. ______________________ Is the light in region D best described as a primary or secondary color?

9. ______________________ The color in region B is the complement to which color?

10. ______________________ The color in region C is the complement to which color?

11. ______________________ The color in region D is the complement to which color?

Answer the following questions.

12. ______________________ What does a primary pigment absorb from white light?

13. ______________________ What does a secondary pigment absorb from white light?

14. ______________________ Is the absorption of light to form pigment colors an additive or subtractive process?

15. ______________________ What colors are the three primary pigments?

16. ______________________ What colors are the three secondary pigments?

17. ______________________ What color(s) does yellow pigment absorb from light.

18. ______________________ What color(s) does yellow pigment reflect?

19. ______________________ What color(s) does red pigment absorb from light?

20. ______________________ What is the complementary pigment to cyan pigment?

21. ______________________ What color would result from mixing two complementary pigments?

In your textbook, read about polarization of light on pages 443–444.
For each statement below, write* true *or rewrite the italicized part to make the statement true.

22. ______________________ Polarized sunglasses absorb light by filtering out light that is horizontally polarized by *reflection* off the surfaces of roads.

23. ______________________ The direction of a polarizing medium *horizontal* to long molecules is called the polarizing axis.

24. ______________________ Ordinary light contains waves vibrating in every direction *perpendicular* to its direction of travel.

25. ______________________ A polarizing medium placed in a beam of ordinary light allows only the components of the waves moving *at a 90° angle* to the polarizing axis pass through.

26. ____________________ On average, a polarizing filter will reduce the intensity of light passing through by *75 percent*.

27. ____________________ Light that has passed through a polarizing filter vibrates *in a single plane*.

28. ____________________ Partially polarized light will appear *brighter* to an observer looking through a polarizing filter.

29. ____________________ When two polarizing filters are placed perpendicular to each other, *all of the light can come through*.

In your textbook, read about the speed of a light wave on pages 445–447.

For each statement below, write* true *or rewrite the italicized part to make the statement true.

30. ____________________ All colors of light travel at *the same speed* in a vacuum.

31. ____________________ When you know the *frequency* of a *light wave* in a vacuum, you can calculate its wavelength.

32. ____________________ When a wavelength of light increases, the light is shifted *toward blue*.

33. ____________________ The frequency of a sound that a listener hears changes if either the source of that sound or the listener of that sound is moving. This same phenomenon *does not hold* for the frequency of a light wave.

34. ____________________ When the observed wavelength of light is longer and the frequency is lower, the light source and the observer are moving *toward* each other.

35. ____________________ Scientists can ascertain the elements that are present on distant galaxies by observing the *wavelengths of light* they emit.

36. ____________________ The Doppler effect of *sound* can involve only the velocities of the source and the observer relative to each other.

37. ____________________ Light waves are Doppler shifted *based upon the relative speed* of the observer and the source of light.

Date ____________ Period ____________ Name ____________________

CHAPTER 16

Section 16-1 Quiz

1. A light bulb emitting 1750 lm of luminous flux shines on a book that is 3.0 m away.

a. What is the illumination on the book?

____

b. In general terms, how will illuminance change as a person in the room moves the book closer to the light bulb? How does this illustrate an inverse-square relationship?

____

____

____

____

2. Explain how transparent and opaque media are similar. Explain how they are different.

____

____

____

____

3. Light travels from the Sun to Earth in 8.3 min. Given that the speed of light is 3.00×10^8 m/s, what is the distance in meters between the Sun and Earth?

Date ________________ Period ________________ Name ______________________________

CHAPTER 16

Section 16-2 Quiz

1. Describe a phenomenon of light that supports the wave model as a means to describe light's behavior.

2. Is color a property of an object? Explain your answer.

3. How do polarizing sunglasses reduce the amount of light that reaches the eye?

4. Edwin Hubble proposed that the universe is expanding. How did he support this assertion?

Date ____________ Period ____________ Name ______________________

CHAPTER 16

Reinforcement

Materials

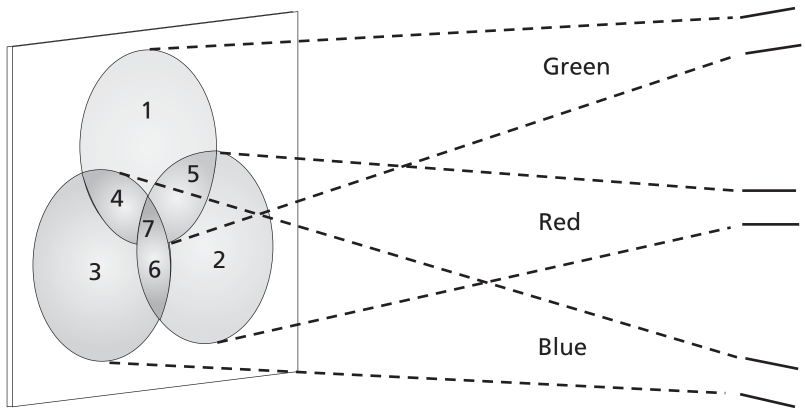
Materials for each group of four

- three flashlights
- one each: red, green, and blue translucent filters
- three rubber bands
- one sheet of white paper

Adding Colors

When beams of light of different wavelengths; that is, different colors, are projected on a white screen, they combine to produce new colors.

Procedure



1. Attach the red, green, and blue filters to your flashlights with rubber bands.
2. Shine the three colored lights on the white paper to create the pattern shown in the diagram.

Results

Use your results to complete the table.

Segment	1	2	3	4	5	6	7
Color							
Complementary Color							

1. Which colors are primary? Why are they called primary colors?

____

____

2. Which colors are secondary? Why are they called secondary colors?

____

____

Date ____________ Period ____________ Name ____________________

CHAPTER 16

Enrichment

Materials

Materials for each group of four

- one small flashlight
- one red, green, or blue translucent filter
- one candle
- one box of matches
- one piece of cardboard with a slit cut in the middle
- one lens
- one prism
- one sheet of white paper to use as a screen

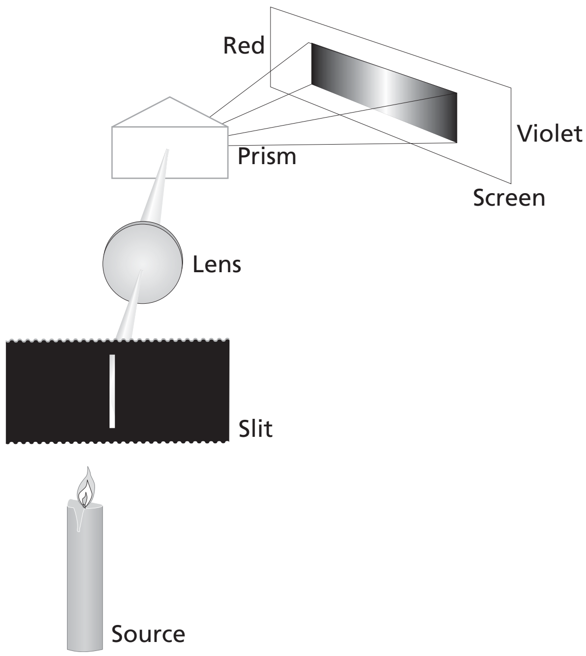
Making a Spectrograph

Elements that are present in the stars of galaxies emit specific wavelengths of light. Scientists use the spectrographs they obtain from the stars to determine their physical makeup. You can observe the same phenomenon here on Earth.

Candles are made from carbon-based waxes. Flashlight bulbs emit light from a wire made of the element tungsten. In this investigation you will observe whether the types of light these two materials emit create different spectrographs.

Procedure

1. Arrange the materials as depicted in the diagram below. One group member will need to hold the piece of cardboard with the slit.
2. Light the candle, and observe the spectrograph the light creates.
3. Shine the flashlight through the slit, and observe the spectrograph the light creates.
4. Place a colored translucent filter on the flashlight. Observe the spectrograph the colored light creates.



Results

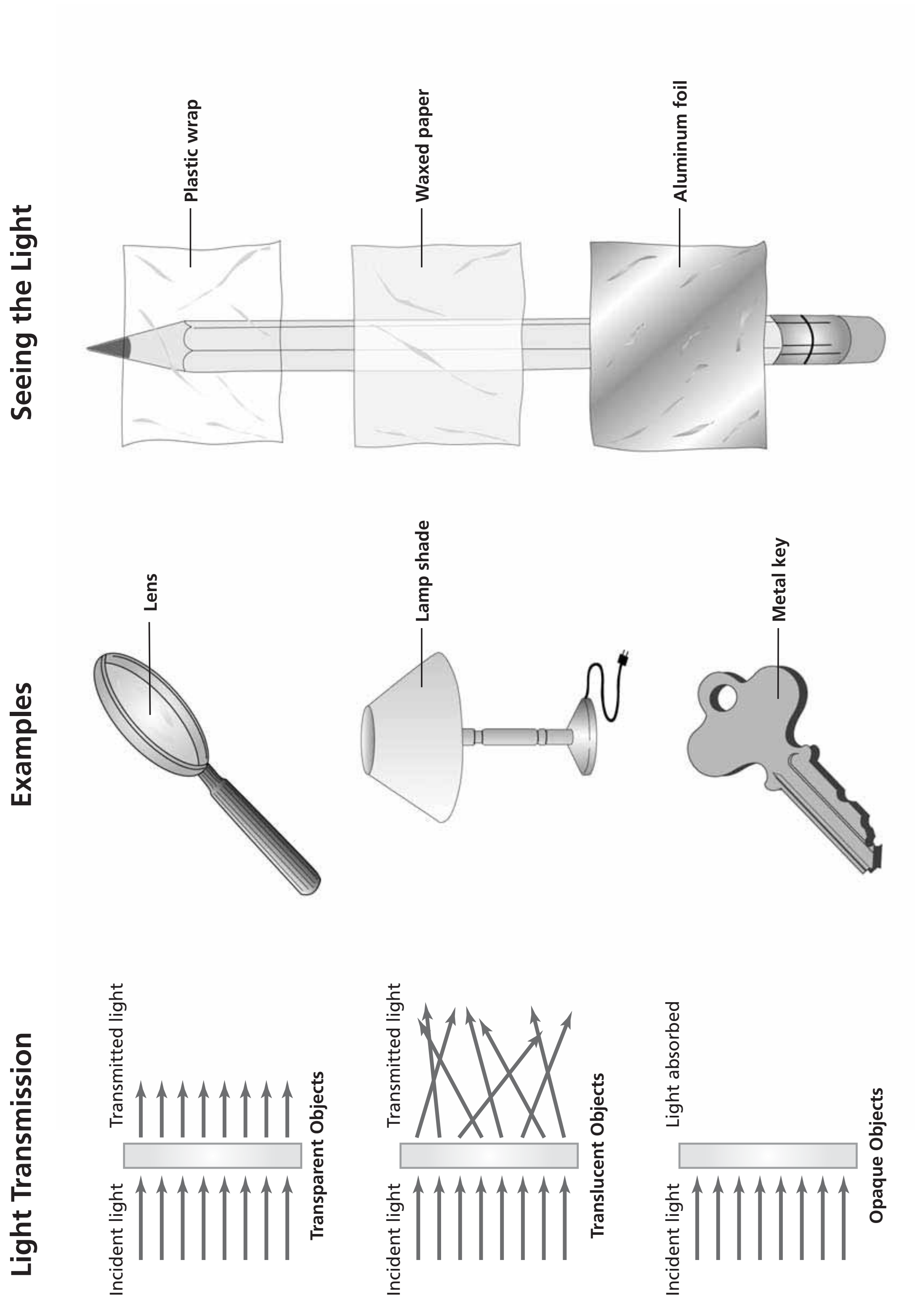
1. Describe what you observed when you shined each light source through the spectrograph.

2. Create a diagram of each spectrograph you observed.

3. Use what you have learned about the component wavelengths of white light to explain your observations.

Transparency 16-1

Light Transmission Through Objects



Date ____________ Period ____________ Name ________________________

16 Transparency 16-1 Worksheet

Light Transmission Through Objects

1. What is a transparent medium?

2. What happens to light rays when they hit a transparent medium?

3. Give an example of a transparent medium other than the one shown.

4. What do you see when you try to look at a pencil through a transparent medium?

5. What is a translucent medium?

6. What happens to light rays when they hit a translucent medium?

7. Give an example of a translucent medium other than the one shown.

8. What do you see when you try to look at a pencil through a translucent medium?

9. What is an opaque medium?

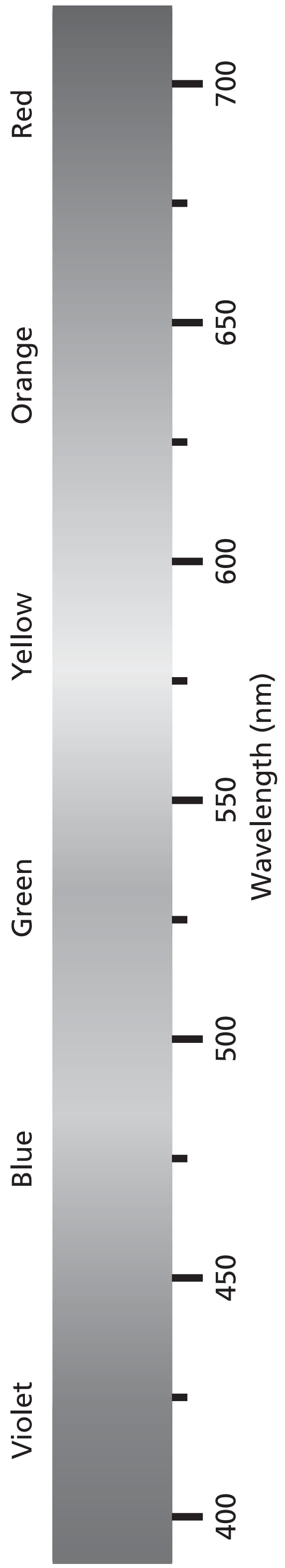
10. What happens to light rays when they hit an opaque medium?

11. Give an example of an opaque medium other than the one shown.

12. What do you see when you try to look at a pencil through an opaque medium?

Transparency 16-2

Electromagnetic Spectrum



Date ____________ Period ____________ Name ______________________

16 Transparency 16-2 Worksheet

Electromagnetic Spectrum

1. In what direction does wavelength increase on this scale?

____

2. Which color has a shorter wavelength: green light or orange light?

____

3. Which color has a higher frequency: yellow light or blue light? Explain your reasoning.

____

____

____

____

4. List the colors of visible light in order of decreasing frequency.

____

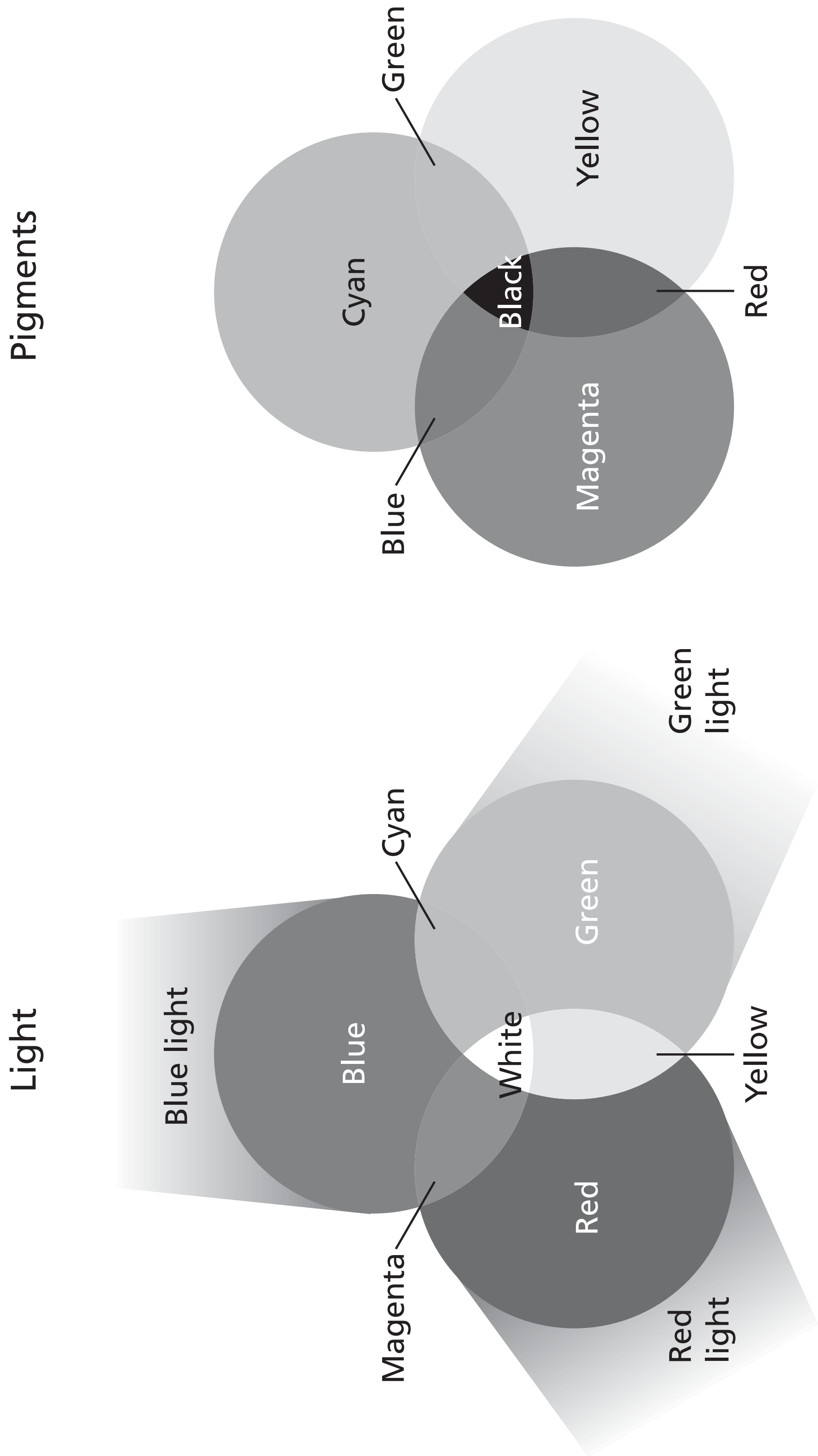
5. In a vacuum, all of the colors of light travel at the same speed. Arrange the following colors in order of decreasing wavelength: orange, violet, green, yellow.

____

6. The wavelength changes if light enters another medium. In glass, for example, the speed of light is about 2.0×10^8 m/s. Calculate the wavelength of red light in glass if its wavelength in a vacuum is 750 nm.

Transparency 16-3

Mixing Colors



Date ______________ Period ______________ Name ______________________

16 Transparency 16-3 Worksheet

Mixing Colors

1. What are the primary colors of light?

2. What are the secondary colors of light?

3. What happens when you combine all three primary colors of light?

4. What are the primary pigment colors?

5. What are the secondary pigment colors?

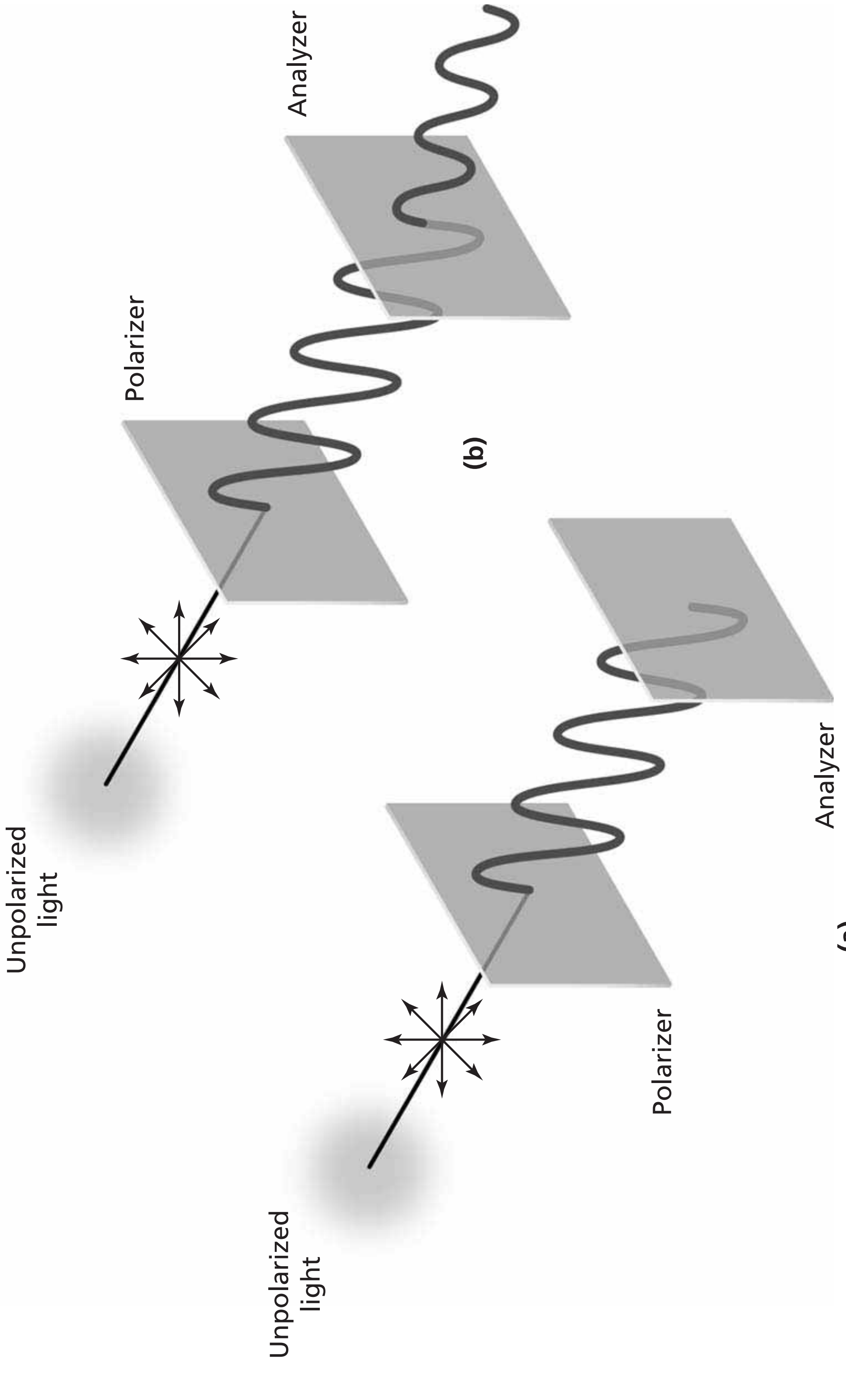
6. What happens when you combine all three primary pigment colors?

7. Why is combining pigments considered a subtractive process?

8. Why are the secondary colors given that name?

Transparency 16-4

Polarizing Light



Date ______________ Period ______________ Name ______________________________

16 Transparency 16-4 Worksheet

Polarizing Light

1. Describe the vibrating of the unpolarized light.

2. What is a polarizer?

3. What is an analyzer?

4. What name is also given to both polarizers and analyzers?

5. What do the double-headed arrows on the polarizers and analyzers represent?

6. What happens to the unpolarized light that enters the polarizers?

7. Compare the orientations of the two polarizing axes in **Figure a**.

8. In Figure a, what happens to the light that reaches the analyzer? Why?

9. Compare the orientations of the two polarizing axes in **Figure b**.

10. In Figure b, what happens to the light that reaches the analyzer? Why?

Date ____________ Period ____________ Name ______________________

CHAPTER
16

Chapter Assessment

Light

Understanding Physics Concepts

Circle the letter of the choice that best completes the statement or answers the question.

1. What determines the color of light?

a. wavelength
b. temperature
c. surface
d. distance

2. Which of these colors of light has the longest wavelength?

a. black
b. violet
c. green
d. red

3. Which of these properties of light is a constant?

a. wavelength
b. speed in a vacuum
c. frequency
d. amplitude

4. The rate, in lumens, at which light is emitted from a light bulb is the bulb's _____.

a. luminous flux
b. illuminance
c. frequency
d. luminous intensity

5. Which best describes the relationship between distance and illuminance?

a. $d = r$
b. $d = r^2$
c. $d = \frac{1}{r}$
d. $d = \frac{1}{r^2}$

6. Very thin, white tissue paper can best be described as _____.

a. transparent
b. translucent
c. opaque
d. luminous

7. Materials that do not allow any transmission of light are described as _____.

a. transparent
b. translucent
c. opaque
d. luminous

8. The mixing of primary colors of light to produce other colors is a(n) _____ process.

a. refractive
b. diffractive
c. subtractive
d. additive

9. Combining the primary colors—red, blue, and green—forms _____ light.

a. no
b. white
c. shifted
d. reflected

10. Polarized light consists of waves _____ in the same place.

a. fixed
b. traveling
c. oscillating
d. combining

For each statement below, write true *or rewrite the italicized part to make the statement true.*

11. ______________________ The clear-edged quality of the shadow that results when you put your hand in the path of light from a flashlight illustrates that light travels in a *curved* line.

12. ______________________ A primary pigment reflects *two* primary colors from white light.

13. ______________________ Newton called the ordered arrangement of colors a(n) *oscillation*.

14. ______________________ The waves that cannot pass through a polarizing filter are those that are vibrating *parallel* to the polarizing axis.

Write the term that best completes the statement. Use each term once.

diffraction
glass prism
illuminated source
inverse-square
lumens
lux
opaque
ray model of light
short wavelength
speed of light

15. ______________________ The unit that measures the amount of light that comes out of a lamp is _____.

16. ______________________ The unit that describes the rate at which light strikes a screen is _____.

17. ______________________ The type of medium that best describes a concrete wall in relation to light is _____.

18. ______________________ The end of the visible spectrum relating to light reflected by a violet flower is described as _____.

19. ______________________ The tool Sir Isaac Newton used to reveal the spectrum of colors in white light is a(n) _____.

20. ______________________ The description that light travels along a straight path is the _____.

21. ______________________ The phenomenon that results from light waves being cut by an edge is _____.

22. ______________________ The term that best describes a bicycle reflector in relation to light is a(n) _____.

23. ______________________ The relationship between distance and a point light source is _____.

24. ______________________ A universal constant with its own special symbol is the _____.

Thinking Critically

Answer the following questions. Use complete sentences.

1. What are the two models of light? How does each model explain part of the behavior of light?

2. Contrast luminous flux, luminous intensity of a point source, and illuminance.

3. Describe the relationship between the illuminance on a surface and the distance the surface is from the light source.

4. Danish astronomer Ole Roemer (1644–1710) was the first to prove that light moves at finite speed. Would he have been able to measure time between the eclipses of Jupiter's moon Io, if light traveled instantaneously? Explain your answer.

5. Why does a dandelion appear yellow in white light? Is the process additive or subtractive?

6. How is a dye different from a pigment? How are the two similar?

7. How can you tell whether light is polarized?

8. Explain the conceptual difference between the refraction and diffraction of light.

9. Consider parallax when observing two objects on the horizon. If one of the objects shows a greater apparent shift in position, what does that tell you about its position relative to the other object? If the two objects are stars, then explain which one's light takes the longest to reach you.

10. Does the Doppler shift affect the speed of light in a vacuum? Explain your answer.

Applying Physics Knowledge

Answer the following questions. Show your calculations.

1. What is the frequency of light with a wavelength of 7.00×10^{-7} m?

2. What is the illuminance, in lux, for a piece of paper on a table 2.0 m from a point light source that is producing 1600 lm of luminous flux?

3. A light bulb is 4.1 m from a surface. How much luminous flux must the bulb produce if the illuminance required is 22 lx?

4. What is the luminous intensity, in candelas, of a bulb with 3.00×10^{3} lm of luminous flux?

5. A sodium vapor lamp emits light waves with a frequency of 5.26×10^{14} Hz. What is the wavelength of the light?

6. Approximately where in the spectrum is light that has a frequency of 5.50×10^{14} Hz?

7. What is the distance of a book from a lamp that produces 1750 lm of flux when the illuminance on the book is 22 lx?

8. One watt of electromagnetic energy is equivalent to 510 lm of luminous flux. What is the illuminance on a book due to a fluorescent bulb that is 2.0 m from the book that uses 40 W of electric power? Assume that the bulb operates at 20 percent efficiency. In other words, only 0.2 of each watt of electric power provided to the bulb is converted to watts of usable electromagnetic energy in the form of light. (Hint: calculate luminous flux first.)

9. Suppose the fluorescent bulb in problem 8 was replaced by a 40-W incandescent bulb at the same distance from the book. Calculate the book's illuminance produced by the incandescent bulb, which operates only at three percent efficiency.

CHAPTER 17

Reproducible Pages Contents

Reflection and Mirrors

Date ______________ Period ______________ Name ______________________

CHAPTER 17

Mini Lab Worksheet

Virtual Image Position

Suppose you are looking at your image in a plane mirror. Can you measure the location of the image?

1. Obtain a camera from your teacher with a focusing ring that has distances marked on it.
2. Stand 1.0 m from a mirror and focus on the edge of the mirror. Check the reading on the focusing ring. It should be 1.0 m.
3. **Measure** the position of the image by focusing the camera on your image. Check the reading on the focusing ring.

Analyze and Conclude

4. How far is the image behind the mirror?

____

____

____

5. Why is the camera able to focus on a virtual image that is behind the mirror even though there is no real object behind the mirror?

____

____

____

Date ____________ Period ____________ Name ____________________

CHAPTER 17

Physics Lab Worksheet

Materials

■ **Do not look at the reflection of the Sun in a mirror or use a concave mirror to focus sunlight.**

- concave mirror
- flashlight
- screen support
- mirror holder
- two metersticks
- four meterstick supports
- screen
- lamp with a 15-W lightbulb

Concave Mirror Images

A concave mirror reflects light rays that arrive parallel to the principal axis to the focal point. Depending on the object position, different types of images can be formed. Real images can be projected onto a screen while virtual images cannot. In this experiment you will investigate how changing object positions affect the image location and type.

Question

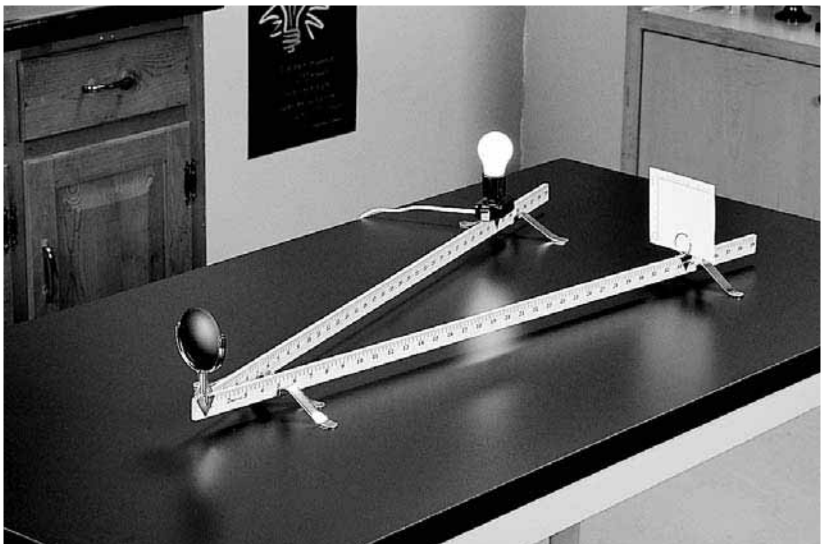
What are the conditions to produce real and virtual images using a concave mirror?

Objectives

- **Collect and organize data** of object and image positions.
- **Observe** real and virtual images.
- **Summarize** conditions for production of real and virtual images with a concave mirror.

Procedure

1. Determine the focal length of your concave mirror by using the following procedure. ***CAUTION: Do not use the Sun to perform this procedure.*** Reflect light from a flashlight onto a screen and slowly move the screen closer or farther away from the mirror until a sharp, bright image is visible. Measure the distance between the screen and the mirror along the principal axis. Record this value as the actual focal length of the mirror, f.



Data Table				
Trial	d_o (cm)	d_i (cm)	h_o (cm)	h_i (cm)
1				
2				
3				
4				
5				

Calculation Table					
Trial	$\frac{1}{d_o}$ (cm^{-1})	$\frac{1}{d_i}$ (cm^{-1})	$\frac{1}{d_o} + \frac{1}{d_i}$ (cm^{-1})	f_{calc} (cm)	% error
1					
2					
3					
4					
5					

2. On the lab table, set up two metersticks on supports in a V orientation. Place the zero measurement ends at the apex of the two metersticks.

3. Place the mirror in a mirror holder and place it at the apex of the two metersticks.

4. Using the lamp as the object of the reflection, place it on one meterstick at the opposite end from the apex. Place the mirror and the screen, supported by a screen support, on the other meterstick at the opposite end from the apex.

5. Turn off the room lights.

6. Turn on the lamp. ***CAUTION: Do not touch the hot lightbulb.*** Measure object position, d_o, and record this as Trial 1. Measure the object height, h_o, and record it as Trial 1. This is measured as the actual height of the lightbulb, or glowing filament if the bulb is clear.

7. Adjust the mirror or metersticks, as necessary, such that the reflected light shines on the screen. Slowly move the screen back and forth along the meterstick until a sharp image is seen. Measure image position, d_i, and the image height, h_i, and record these as Trial 1.

8. Move the lamp closer to the mirror so that d_o is twice the focal length, f. Record this as Trial 2. Move the screen until an image is obtained on the screen. Measure d_i and h_i, and record these as Trial 2.
9. Move the lamp closer to the mirror so that d_o is a few centimeters larger than f. Record this as Trial 3. Move the screen until an image is obtained on the screen. Measure d_i and h_i, and record these as Trial 3.
10. Move the lamp so that d_o is equal to the f. Record this as Trial 4 data. Move the screen back and forth and try to obtain an image. What do you observe?

    ____

    ____

11. Move the lamp so that d_o is less than f by a few centimeters. Record this as Trial 5. Move the screen back and forth and try to obtain an image. What do you observe?

    ____

    ____

Analyze

1. **Use Numbers** Calculate $1/d_o$ and $1/d_i$ and enter the values in the calculation table.

2. **Use Numbers** Calculate the sum of $1/d_o$ and $1/d_i$ and enter the values in the calculation table. Calculate the reciprocal of this number and enter it in the calculation table as f_{calc}.

3. **Error Analysis** Compare the experimental focal length, f_{calc}, with f, the accepted focal length, by finding the percent error.

   $$\text{percent error} = \frac{|f - f_{calc}|}{f} \times 100$$

Conclude and Apply

1. **Classify** What type of image was observed in each of the trials?

2. **Analyze** What conditions cause real images to be formed?

3. **Analyze** What conditions cause virtual images to be formed?

Going Further

1. What are the conditions needed for the image to be larger than the object?

2. Review the methods used for data collection. Identify sources of error and what might be done to improve accuracy.

Real-World Physics

What advantage would there be in using a telescope with a concave mirror?

Physics Online

To find out more about reflection, visit the Web site: **physicspp.com**

CHAPTER 17

Study Guide

Reflection and Mirrors

Vocabulary Review

Write the term that correctly completes the statement. Use each term once.

concave mirror	**focal point**	**plane mirror**	**spherical aberration**
convex mirror	**image**	**principal axis**	**virtual image**
diffuse reflection	**magnification**	**real image**	
focal length	**object**	**specular reflection**	

1. ____________________ The _____ is a straight line perpendicular to the surface of a spherical mirror that divides the mirror in half.

2. ____________________ Reflection in which rays are reflected in parallel is called _____.

3. ____________________ The combination of image points produced by light rays from an object is called the _____ of the object.

4. ____________________ A(n) _____ is a flat, smooth surface from which light is reflected by regular reflection.

5. ____________________ A source of light rays is called a(n) _____.

6. ____________________ The scattering of light off a rough surface is called _____.

7. ____________________ The reflective surfaces of a(n) _____ have edges that curve toward the observer.

8. ____________________ Diverging light rays produce a(n) _____ of an object.

9. ____________________ At the _____ of a mirror, incident light rays that are parallel to the principal axis converge after reflecting from the mirror.

10. ____________________ A(n) _____ is a reflective surface with edges that curve away from the observer.

11. ____________________ An image formed by the converging of light rays is a(n) _____.

12. ____________________ An effect called _____ makes images formed by some spherical mirrors appear fuzzy.

13. ____________________ The distance from the focal point to a mirror along the principal axis is the _____.

14. ____________________ The amount by which an image is enlarged or reduced relative to an object is called _____.

Section 17.1 Reflection from Plane Mirrors

In your textbook, read about the law of reflection on pages 458–460.

For each statement below, write* true *or rewrite the italicized part to make the statement true.

1. ______________________ The normal is a line *parallel* to a surface.

2. ______________________ The reflection of light is *three dimensional*.

3. ______________________ The angle of incidence equals the angle of *reflection*.

4. ______________________ A mirror causes *diffuse* reflection.

5. ______________________ A rough surface causes *specular* reflection.

6. ______________________ Even seemingly *smooth* surfaces can cause diffuse reflection.

Write the term that correctly completes the statement.

The behavior of reflected light depends on the type of light and the (**7**) ______________________ at which the light strikes the surface. The angle of incidence is measured between the (**8**) ______________________ ray and the (**9**) ______________________. The angle of reflection is measured between the (**10**) ______________________ ray and the (**11**) ______________________. The law of reflection can be explained in terms of the (**12**) ______________________ model of light. Each point along a wave front reflects off a surface at the same (**13**) ______________________ as the preceding point. When a beam of light strikes a rough surface, it reflects at (**14**) ______________________ angles, producing (**15**) ______________________ reflection. When a beam of light strikes a very smooth surface, the reflected rays are (**16**) ______________________ to each other, producing (**17**) ______________________ reflection.

In your textbook, read about plane-mirror images on pages 461–463.

Answer the following questions. Use complete sentences.

18. In the context of mirrors, what does the term *object* mean?

19. What type of image does a plane mirror produce? Where is this image?

20. Why does a plane-mirror image appear to be behind the mirror?

21. What does the term *mirror image* mean?

22. How can you prove that a plane-mirror image is the same size as the object and is at the same distance behind the mirror as the object is in front of the mirror?

23. Does a plane mirror reverse an image left to right? Why or why not?

Section 17.2 Curved Mirrors

In your textbook, read about concave mirrors on page 464.

For each statement below, write* true *or rewrite the italicized part to make the statement true.

1. ______________________ The properties of a concave mirror depend on its *size*.

2. ______________________ Rays *perpendicular* to the principal axis of a spherical concave mirror are reflected and converge at or near the focal point.

3. ______________________ The focal length of a spherical concave mirror is *half* the radius of curvature.

In your textbook, read about methods of finding images on pages 465–470.

Circle the letter of the choice that best completes the statement or answers the question.

4. The mirror equation states that ______.

a. $f = d_i + d_o$ **b.** $\frac{1}{f} = d_i + d_o$ **c.** $f = \frac{1}{d_i} + \frac{1}{d_o}$ **d.** $\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$

5. The equation for magnification is ______.

a. $m \equiv h_i + h_o$ **b.** $m \equiv h_i - h_o$ **c.** $m \equiv \frac{h_i}{h_o}$ **d.** $m \equiv \frac{h_o}{h_i}$

6. A ______ indicates that an image produced by a concave mirror is upright.

a. positive value for h_i **c.** positive value for d_i

b. negative value for h_i **d.** negative value for d_o

7. Magnification, m, is equal to ______.

a. $\frac{d_o}{d_i}$ **b.** $-\frac{d_o}{d_i}$ **c.** $\frac{d_i}{d_o}$ **d.** $-\frac{d_i}{d_o}$

8. A ______ indicates that an image produced by a concave mirror is virtual.

a. positive value for h_o **c.** positive value for d_i

b. negative value for h_i **d.** negative value for d_i

9. If an object is placed at the focal point of a concave mirror, where will the image be?

a. also at the focal point **c.** at infinity

b. at the center of curvature **d.** at the surface of the mirror

10. Why do parabolic mirrors not suffer from spherical aberration?

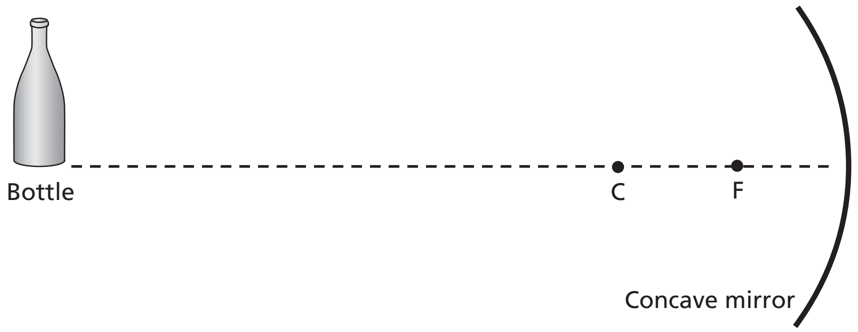
a. All parallel rays are reflected through a single point.

b. All parallel rays focus on infinity.

c. Parabolic mirrors use a secondary mirror for correction.

d. Parabolic mirrors have a virtual focus point.

The diagram below shows a bottle and a concave mirror. Refer to the diagram to answer questions 11–18.



11. What does the letter F stand for?

12. What does the dashed line represent?

13. Under what condition will rays be reflected through Point F?

14. Approximately where will the image be relative to Points C and F?

15. Will the value of d_i be positive or negative? Why?

16. Will the image be real or virtual? Why?

17. Will the image be reduced or enlarged? Why?

18. Will the value of h_i be greater or lower than that of h_o? Why?

In your textbook, read about convex mirrors on pages 471–473.

For each statement below, write* true *or rewrite the italicized part to make the statement true.

19. ____________________ The focal length of a convex mirror is *negative*.

20. ____________________ Rays reflected from a convex mirror always *converge*.

21. ____________________ Convex mirrors reflect an *enlarged* field of view.

22. ____________________ The images produced by convex mirrors are *real* images.

23. ____________________ When the magnification is negative, the image is *upright*.

24. ____________________ When compared to the size of surrounding objects, the images produced by convex mirrors are always *larger*.

Answer the following questions. Use complete sentences.

25. What type of image does a convex mirror produce? Why?

26. Why do objects viewed in convex mirrors appear farther way than they really are?

27. What useful properties do convex mirrors have?

28. Why is the focal length of a convex mirror negative?

29. How are the images formed by convex mirrors and plane mirrors similar? How are they different?

Date ______________ Period ______________ Name ________________________

CHAPTER
17

Section 17-1 Quiz

1. The law of reflection applies to both rough and smooth surfaces. Why then do rough and smooth surfaces reflect light differently?

____

____

____

2. Describe the characteristics of an image produced by a plane mirror.

____

____

____

3. A beam of light strikes a mirror at an angle of 47° relative to the surface of the mirror. What angle does the reflected beam make with the normal?

4. A 1.5-m tall woman stands 2.5 m from a plane mirror. Where is her image and how tall is it?

CHAPTER 17

Section 17-2 Quiz

1. What type of image is produced by a concave mirror if the object position is greater than the focal length? If the object position is less than the focal length?

2. What type of image is produced by a convex mirror? Identify one application of convex mirrors.

3. A dog standing 30 cm from a spherical concave mirror produces an image 15 cm in front of the mirror. What is the focal length of the mirror?

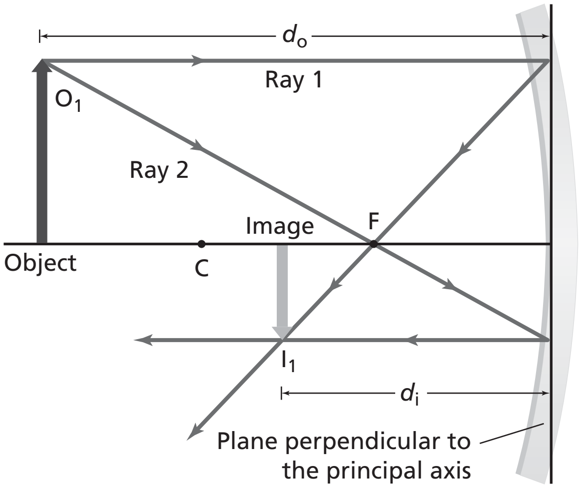
4. If the dog in Question 3 is 0.75 m tall, how tall is its image?

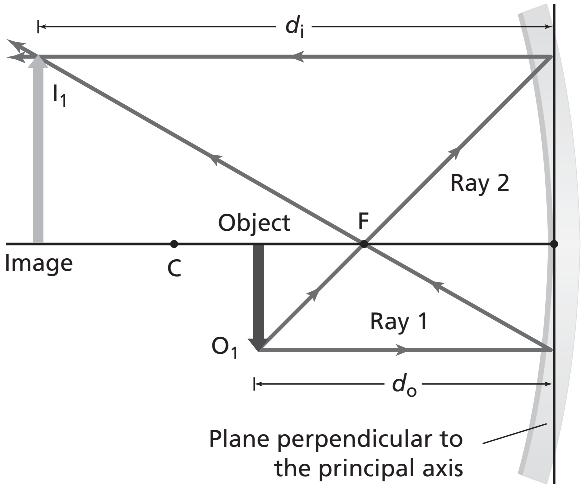
CHAPTER 17

Reinforcement

Finding the Image in a Concave Mirror

Refer to the ray diagrams to answer questions 1–5.





1. How is a ray diagram used to determine the position of an image in a spherical concave mirror?

____

____

____

2. What other attribute of an image can be determined by using a ray diagram?

____

3. In what way is the ray diagram method a simplification of the way an image is formed?

____

____

4. If an object position is more than twice the focal length of the mirror, what properties does the image have?

____

____

5. If an object is between the focal length and the center of curvature of the mirror, what properties does the image have?

____

____

Date ____________ Period ____________ Name ______________________

CHAPTER 17

Enrichment

Materials

- 2 index cards
- 1 m of string
- small mirror
- masking tape
- protractor
- flashlight that projects a narrow beam

Testing the Law of Reflection

The law of reflection says that the angle of incidence is equal to the angle of reflection. How do you know this law is true?

Procedure

Use the materials listed to design an experiment to test the law of reflection. Test several angles, with multiple trials for each angle. Make careful notes about your experiments. Use the table below to record data.

Data Table

		$\Delta\theta_i$		$\Delta\theta_r$		
Trial	$\Delta\theta_{mirror}$	**Initial**	**Final**	**Initial**	**Final**	$\Delta\theta_r$
1						
2						
3						
4						
5						

Results

1. What is your hypothesis?

____

____

____

2. Describe the design of your experiment.

3. What percentage of your experimental trials supported your hypothesis?

4. What variables might have affected your results?

5. Does the distance the light beam travels influence the validity of the law of reflection? Explain your answer.

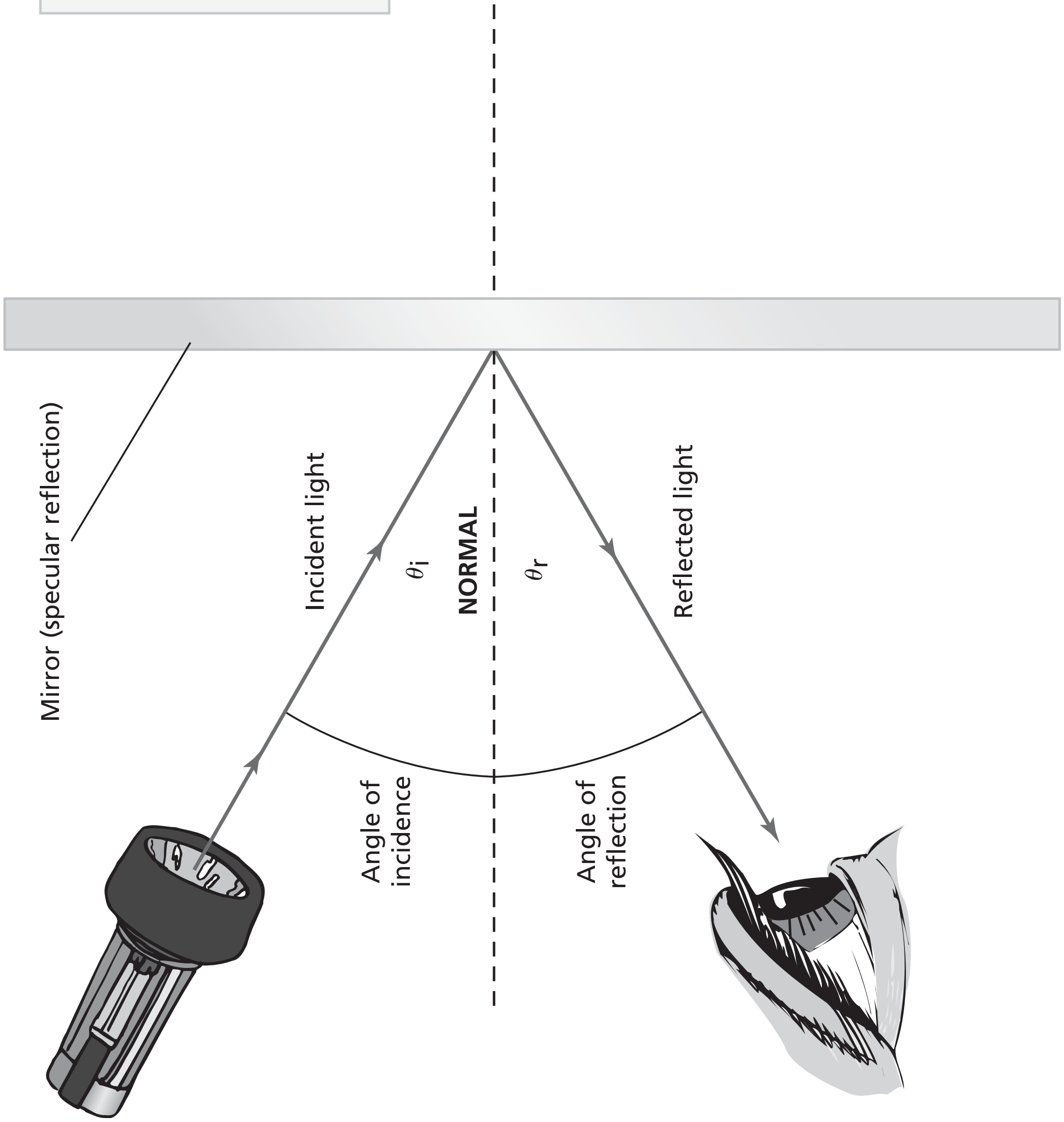
Transparency 17-1

Law of Reflection

Law of Reflection

$\theta_i = \theta_r$

The angle of incidence is equal to the angle of reflection.



Date ____________ Period ____________ Name ________________________

17 Transparency 17-1 Worksheet

Law of Reflection

1. What is the normal?

2. What is the angle of incidence?

3. What is the angle of reflection?

4. What does the law of reflection state?

5. If the angle of incidence in the drawing is 30°, what is the angle of reflection?

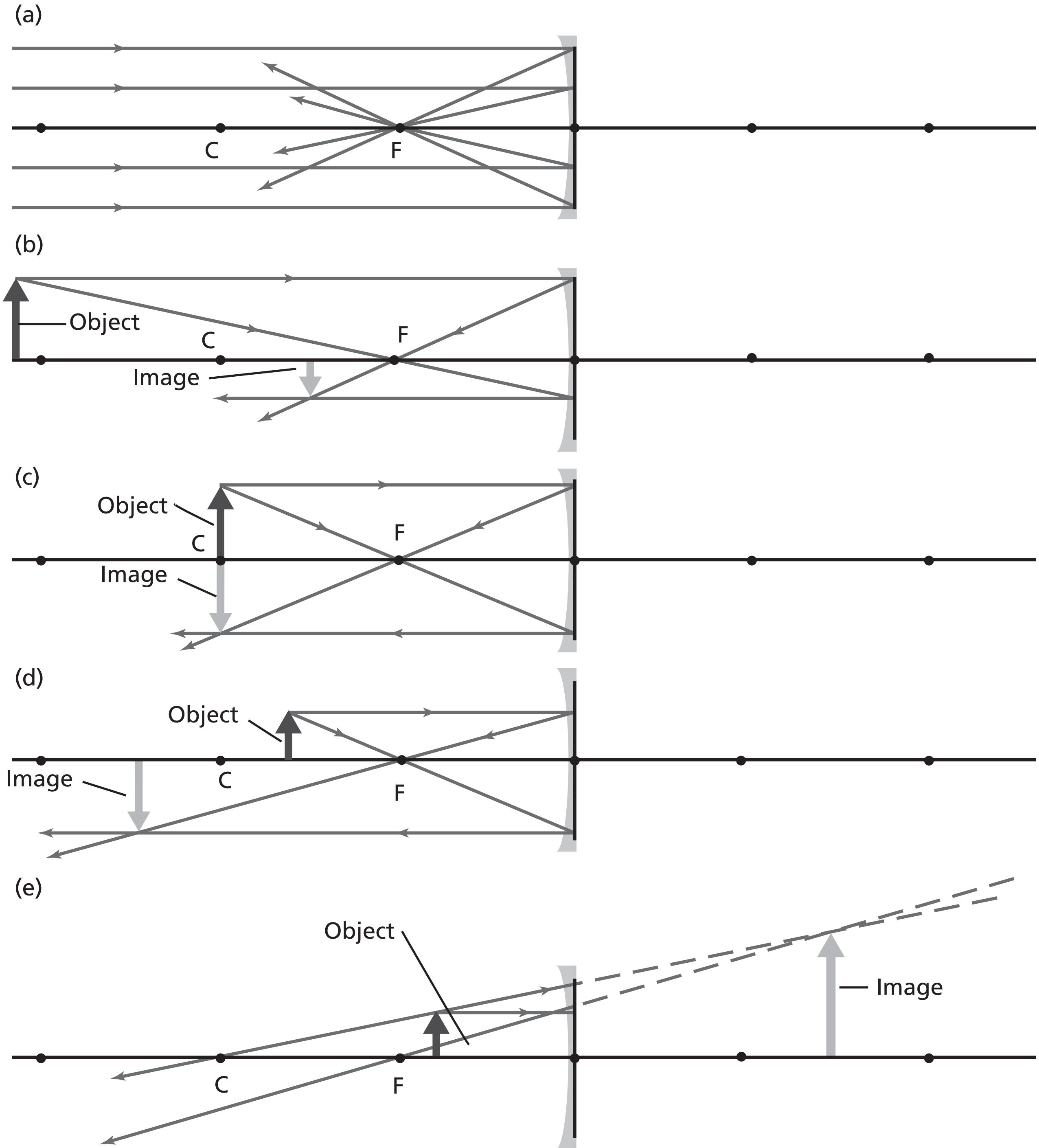
6. Even though light waves travel in three dimensions, a reflecting ray can be drawn on a page. Why is this true?

7. Can you tell what type of reflection is occurring? If not, what would you need to observe in order to determine the type of reflection? Explain your answer.

CHAPTER 17

Transparency 17-2

Image Formation by Mirrors



Date ____________ Period ____________ Name ______________________

17 Transparency 17-2 Worksheet

Image Formation by Mirrors

1. What type of mirror is shown here?

2. What do C and F represent?

3. When an object is very far away, where is light from it focused by a mirror?

4. As the object moves from very far away to very close to F, how does the image produced by a mirror change? Is it a real or a virtual image?

5. What might you do to see the images produced by this mirror?

6. When does an object's size equal the image size for a mirror?

7. What happens to the image when the object is between F and the mirror?

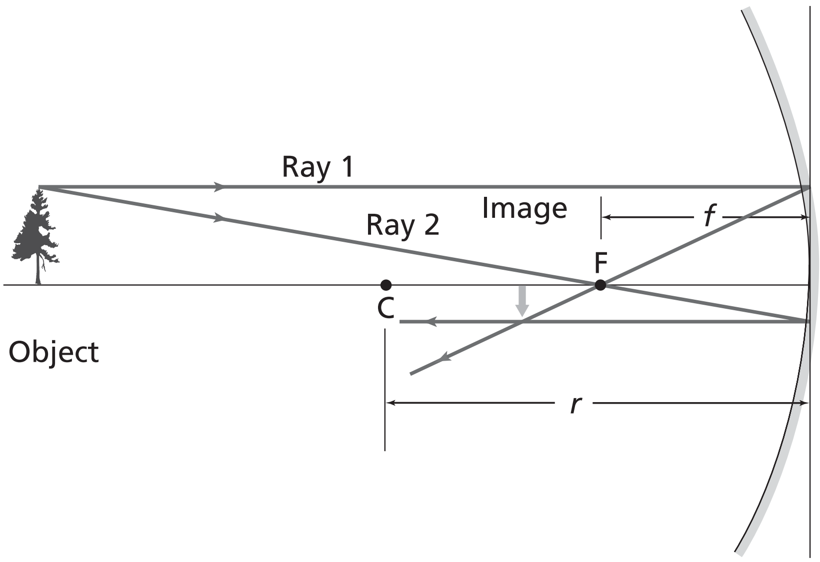
8. What special use would this mirror have? Where would you have to be to see yourself in it?

9. How would you use the mirror to make a spotlight?

CHAPTER 17 Transparency 17-3

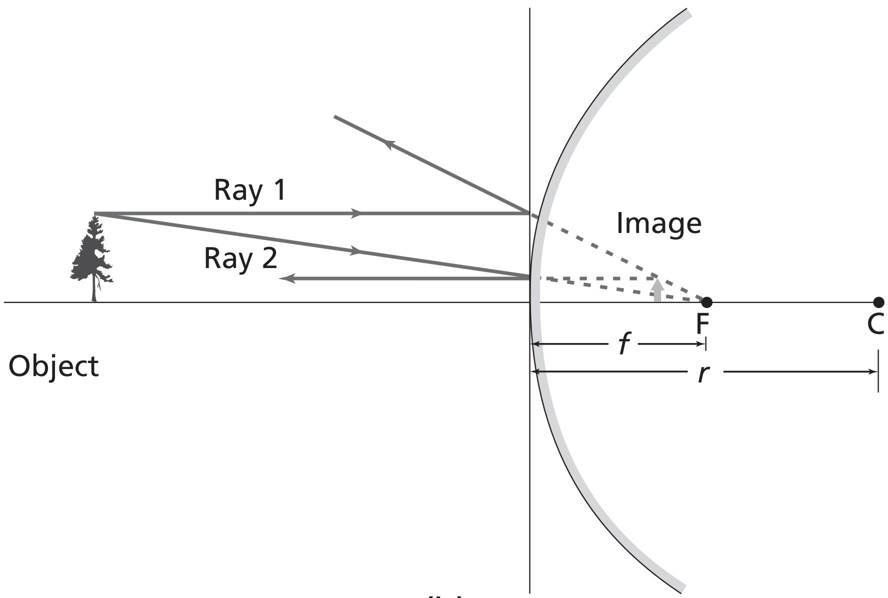
Image Formation by Curved Mirrors

Spherical Concave Mirror



(a)

Spherical Convex Mirror



(b)

Date ____________ Period ____________ Name ____________________

17 Transparency 17-3 Worksheet

Image Formation by Curved Mirrors

1. What is the line that passes through C and F called?

2. What happens to the rays that reflect from the concave mirror?

3. What does your answer to problem 2 tell you about the image formed by a concave mirror?

4. How could you test your answer to problem 3?

5. What happens to the rays that reflect from the convex mirror?

6. What do the dashed lines behind the convex mirror represent?

7. What do your answers to problem 5 and problem 6 tell you about the image formed by a convex mirror?

8. How could you test your answer to problem 6?

9. What are two ways you can determine the magnification of an image?

Date ________ Period ________ Name ________________

CHAPTER 17

Chapter Assessment

Reflection and Mirrors

Understanding Physics Concepts

Circle the letter of the choice that best completes the statement or answers the question.

1. The focal length of a spherical mirror equals ______.

a. the radius of curvature

b. twice the radius of curvature

c. half the radius of curvature

d. half the length of the principal axis

2. When a real image is formed, ______.

a. light rays seem to diverge behind the mirror

b. light rays converge at the image

c. the image cannot be projected on a screen

d. the image is always inverted

3. If an object is between a concave mirror and its focal point, the image will be ______.

a. real and smaller than the object

b. real and larger than the object

c. virtual and smaller than the object

d. virtual and larger than the object

4. Which surface would produce specular reflection of light?

a. white construction paper

b. a telescope mirror

c. a piece of black cloth

d. a concrete sidewalk

For each statement below, write true *or rewrite the italicized part to make the statement true.*

5. ________________ The angle of incidence is always *less than* the angle of reflection.

6. ________________ Rays parallel to the principal axis of a spherical *convex* mirror converge at the focal point.

7. ________________ *Magnification* is defined as the image height divided by the object height.

8. ________________ *Parabolic* mirrors are often used in telescopes.

9. ________________ A single concave mirror produces a virtual image that is *upside-down* when the object position is lss than the focal length.

10. ________________ By forming smaller images, convex mirrors makes images seem *farther* away.

Answer the following questions. Use complete sentences.

11. What happens to a narrow light beam that enters parallel to the principal axis of a spherical concave mirror?

12. What happens to a narrow light beam that passes through the focal point of a concave mirror before being reflected?

13. Compare and contrast spherical concave and spherical convex mirrors. Describe what types of images each mirror produces and under what conditions.

14. What is the difference between specular and diffuse reflection?

15. In many cars the passenger-side rear-view mirror has a warning that reads, "Objects may be closer than they appear." Is the mirror concave or convex? Explain how you know.

Thinking Critically

Answer the following questions. Show your calculations.

1. A thimble is 32.0 cm from a spherical concave mirror. The focal length of the mirror is 11.0 cm. What is the image position?

2. If the thimble in Question 1 is 2.50 cm tall, how tall is the image of the thimble? What is its orientation? Draw a diagram.

3. What is the magnification of the image in Question 2?

4. Is the image of the thimble in Question 1 real or virtual? How do you know?

   ____

   ____

5. A 1.1-m tall child is standing 6.0 m from a spherical convex mirror. The child's image is 0.40 m in front of the mirror. What is the image height? Draw a diagram.

6. What is the magnification in Question 5?

7. What is the focal length of the mirror in Question 5?

8. Would it be possible to view your body from head-to-toe, while standing in front of a plane mirror that is only half as tall as you? Explain your answer and include a diagram.

9. A convex security mirror at a shopping mall shows a person who appears to be 0.18 m tall (image height). The focal length of the mirror is −0.50 m and the person is standing 5.0 m from the mirror. How tall is the person? Show your calculations.

10. How does a large curved mirror make an image appear brighter?

Applying Physics Knowledge

Answer the following questions. Use complete sentences.

1. Both real and virtual images can be seen by a person looking at mirrors. Can both types of images be projected onto a screen? Why or why not?

2. You are walking down the street and see a vehicle with "ƎƆИAJUBMA" painted on the front. What does this mean and why is it written that way?

3. Explain the operation of mirrors used in stores to observe shoppers.

4. You are designing a telescope. You want to collect as much light as possible and direct it to a point next to the telescope. What sizes and types of mirrors would you use and why? Draw a sketch of your design.

Answer the following questions. Show your calculations.

5. You want to create a 0.035-m tall image of a flower. The flower is 1.00 m tall and 10.0 m in front of a concave mirror. What must the radius of curvature of the mirror be? Draw a diagram.

6. A car's convex mirror has a radius of curvature of 0.80 m. If a 2.0-m high vehicle is 4.6 m from the mirror, find the image position and image height. Is the image real or virtual? Is it upright or inverted? Give reasons for your answers.

____

____

7. You need a mirror to produce an image that is upright with a magnification of 4.0 when it is located 12.0 mm from a jewel. What sort of mirror should you use? What is the radius of curvature? Draw a diagram.

____

CHAPTER 18

Reproducible Pages Contents

Refraction and Lenses

Date ____________ Period ____________ Name ____________________

CHAPTER 18

Mini Lab Worksheet

Lens Masking Effects

What happens when you mask, or cover, part of a lens? Does this cause only part of a real image to be formed by the lens?

1. Stick the edge of a convex lens into a ball of clay and place the lens on a tabletop. ***CAUTION: Lenses have sharp edges. Handle carefully.***
2. Use a small lamp on one side and a screen on the other side to get a sharp image of the lamp's lightbulb. ***CAUTION: Lamps get hot and can burn skin.***
3. **Predict** what will happen to the image if you place your hand over the top half of the lens. This is called masking.
4. **Observe** the effects of masking more of the lens and masking less of the lens.

Analyze and Conclude

5. How much of the lens is needed for a complete image?

____

____

6. What is the effect of masking the lens?

____

____

____

Date ______________ Period ______________ Name ______________________

CHAPTER 18

Physics Lab Worksheet

Materials

■ **Ensure the lamp is turned off before plugging and unplugging it from the electrical outlet.**

■ **Use caution when handling lamps. They get hot and can burn the skin.**

■ **Lenses have sharp edges. Handle carefully.**

- lamp with a flashlight or penlight bulb
- thin convex lens
- meterstick
- lens holder
- index card

Convex Lenses and Focal Length

The thin lens equation states that the inverse of the focal length is equal to the sum of the inverses of the image position from the lens and the object position from the mirror.

Question

How is the image position with a thin convex lens related to the object position and the focal length?

Objectives

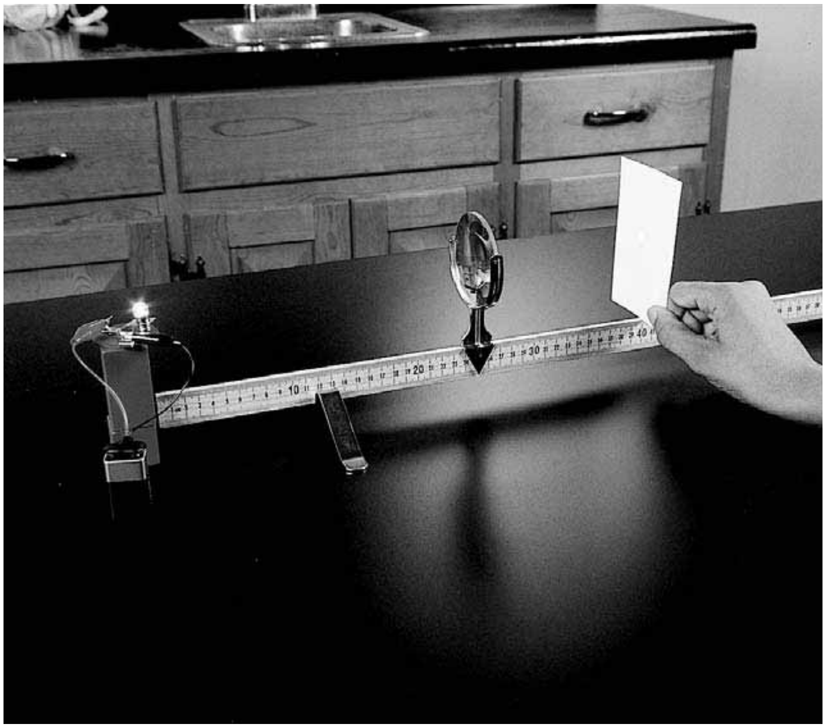
■ **Measure in SI** temperature and mass.

■ **Make and use graphs** to describe the relationship between the image position with a thin convex lens and the object position.

■ **Use models** to show that no matter the image position, the focal length is a constant.

Procedure

1. Place a meterstick on your lab table so that it is balancing on the thin side and the metric numbers are right side up.
2. Place a convex lens in a lens holder and set it on the meterstick on or between the 10-cm and 40-cm marks on the meterstick.



Data Table		
Trial	d_o (cm)	d_i (cm)
1		
2		
3		
4		
5		

Calculation Table				
Trial	$\frac{1}{d_o}$ (cm^{-1})	$\frac{1}{d_i}$ (cm^{-1})	$\frac{1}{d_o} + \frac{1}{d_i}$ (cm^{-1})	f (cm)
1				
2				
3				
4				
5				

3. Turn on the lamp and set it next to the meterstick so that the center of the lightbulb is even with the 0-cm end of the meterstick.
4. Hold an index card so that the lens is between the lamp and the index card.
5. Move the index card back and forth until an upside-down image of the lightbulb is as focused as possible.
6. Record the distance of the lightbulb from the lens (d_o) and the distance of the image from the lens (d_i).
7. Move the lens to another spot between 10 cm and 40 cm and repeat steps 5 and 6.
8. Repeat step 7 four more times.

Analyze

1. **Make and Use Graphs** Make a scatter-plot graph of the image position (vertical axis) versus the object position (horizontal axis). Use a computer or calculator to construct the graph if possible.

2. **Use Numbers** Calculate $1/d_o$ and $1/d_i$ and enter the values in the calculation table.

3. **Use Numbers** Calculate the sum of $1/d_o$ and $1/d_i$ and enter the values in the calculation table. Calculate the reciprocal of this number and enter it in the calculation table as f.

Conclude and Apply

1. **Interpret Data** Looking at the graph, describe the relationship between d_o and d_i.

2. **Interpret Data** Find out the actual focal length of the lens from your teacher. How accurate are your calculations of f?

3. **Interpret Data** How precise are your focal length calculations?

4. **Lab Techniques** Why do you suppose you were instructed not to hold your lens closer than 10 cm or farther than 40 cm?

Going Further

1. Which measurement is more precise: d_o or d_i? Why do you think so?

2. What can you do to make either (or both) measurement(s) more accurate?

Real-World Physics

1. If you were to look through a magnifying glass at an object close up, and then far away, how would the position of the lens from your eye have to change to keep the object in focus?

2. What are two ways in which the image projected onto your retina differs from the object you look at (the lens in your eye is also convex)?

Physics Online

To find out more about lenses and refraction, visit the Web site: **physicspp.com**

Date ____________ Period ____________ Name ____________________

CHAPTER 18

Study Guide

Refraction and Lenses

Vocabulary Review

Write the term that correctly completes the statement. Use each term once.

lens	**convex lens**	**critical angle**
nearsightedness	**index of refraction**	**achromatic lens**
farsightedness	**thin lens equation**	**total internal reflection**
chromatic aberration	**Snell's law of refraction**	**concave lens**
dispersion		

1. ____________________ When light strikes the boundary of a medium with a lower index of refraction at an angle so great that there is no refracted ray, _____ occurs.

2. ____________________ The separation of light into its spectrum is _____.

3. ____________________ The condition where the focal length of the eye is too long is called _____.

4. ____________________ The relationship of the angle of incidence to the angle of refraction is stated in _____.

5. ____________________ A transparent material that has an index of refraction greater than air is a(n) _____.

6. ____________________ _____ is a property of a medium that affects the speed of light in the medium.

7. ____________________ The condition where the focal length of the eye is too short is called _____.

8. ____________________ The _____ describes an angle of incidence at which a refracted ray lies along the boundary of a substance.

9. ____________________ The _____ relates the focal length of a spherical thin lens to the object position and image position.

10. ____________________ A transparent refracting device that is thinner in the middle than at the edges is a(n) _____.

11. ____________________ A transparent refracting device that is thicker in the middle than at the edges is a(n) _____.

12. ____________________ An undesirable effect in which an image created by a lens appears to be ringed with color is _____.

13. ____________________ A lens constructed so as to avoid undesirable color effects is a(n) _____.

Section 18.1 Refraction of Light

In your textbook, read about Snell's law of refraction on pages 486–487.

For each statement below, write* true *or rewrite the italicized part to make the statement true.

1. ______________________ The angle of incidence is the angle between the incoming light beam and the *surface*.

2. ______________________ The speed of light *does not* depend on the medium through which the light is traveling.

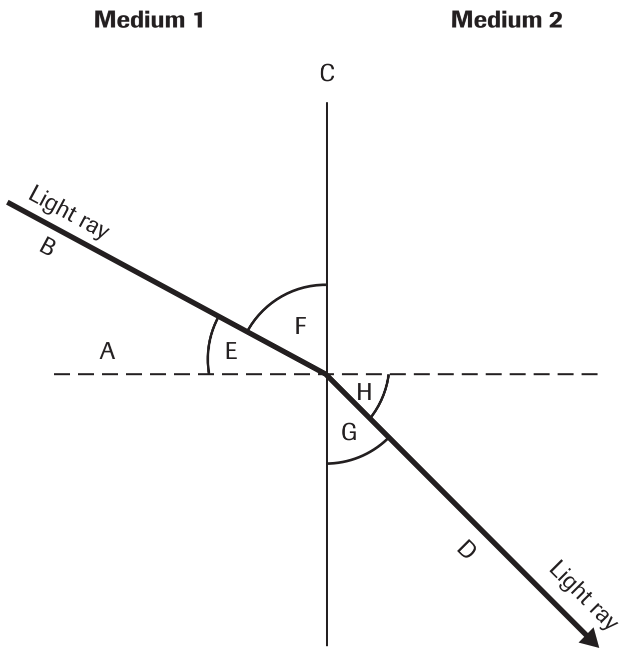
3. ______________________ *Reflection* involves the bending of transmitted light.

4. ______________________ The angle of incidence *differs* from the angle of refraction.

For each description on the left, write the letter of the matching item.

______	**5.** speed of light in a medium	**a.** λ
______	**6.** angle of refraction	**b.** c
______	**7.** frequency of light	**c.** f
______	**8.** angle of incidence	**d.** θ_1
______	**9.** speed of light in a vacuum	**e.** n
______	**10.** wavelength of light	**f.** θ_2
______	**11.** index of refraction	**g.** v

The diagram below represents a light ray passing through two media. Refer to the diagram to answer questions 12–17. Use complete sentences.



12. Which labeled line represents the incident ray? How can you tell?

____

____

13. Which line represents the boundary between the two media?

____

14. Which line represents the normal? How can you tell?

____

____

15. Which line represents the refracted ray? How can you tell?

____

____

16. Which labeled angle is the angle of incidence? How can you tell?

____

____

17. Which labeled angle is the angle of refraction? How can you tell?

____

____

In your textbook, read about total internal reflection on pages 489–490.

***For each statement below, write* true *or* false.**

__________ **18.** The critical angle is the incident angle that causes the refracted light to lie along the boundary.

__________ **19.** The sine of the critical angle for a substance from which light is passing into air is equal to $1.00/n_1$

__________ **20.** Total internal reflection cannot be achieved for light that is passing from water to air.

__________ **21.** All substances have the same critical angle.

__________ **22.** Total internal reflection occurs whenever light passes from one medium to a medium with a higher index of refraction.

__________ **23.** When incident light is at the critical angle, θ_2 equals $0°$.

__________ **24.** The core of an optical fiber is transparent.

__________ **25.** Each time light moving through an optical fiber strikes the outer surface of the fiber, the angle of incidence is larger than the critical angle.

In your textbook, read about mirages and dispersion of light on pages 490–492.

Circle the letter of the choice that best completes the statement or answers the question.

26. As temperature increases, the index of refraction of air _____.

a. increases **c.** remains constant

b. decreases **d.** becomes negligible

27. The mirage effect is caused by _____.

a. total internal reflection

b. polarization

c. temperature differences in index of refraction

d. differences in the speeds of different colors of light

28. Which color of light is bent the most as it goes through a prism?

a. red **c.** green

b. yellow **d.** violet

29. Which color of light is bent the least as it goes through a prism?

a. red **c.** green

b. yellow **d.** violet

30. Light shining through water droplets produces a rainbow because of _____.

a. differences in angles of incidence for light of different colors

b. differences in angles of refraction for light of different colors

c. differences in speed for light of different colors

d. equal indices of refraction for light of different colors

31. A mirage seen by a motorist that appears to be a pool of water is actually caused by light from _____.

a. the ground under the pool **c.** the Sun heating the road

b. the ground around the pool **d.** passing cars

32. In a double rainbow, the second-order rainbow is fainter and has the order of colors _____.

a. wider apart **c.** polarized

b. exactly the same **d.** reversed

Section 18.2 Convex and Concave Lenses

In your textbook, read about types of lenses on pages 493–494.

Answer the following questions. Use complete sentences.

1. What are alternate names for convex and concave lenses? Why are they appropriate?

____

____

____

2. What is the thin lens model?

____

____

In your textbook, read about concave lenses and defects of spherical lenses on pages 498–499.

Circle the letter of the choice that best completes the statement or answers the question.

3. An image formed by a concave lens is always _____.

a. virtual and inverted
c. virtual and upright
b. real and upright
d. real and inverted

4. If the focal point of a concave lens is 12 cm from the lens, what value of *f* should you use in the thin lens equation?

a. 12 cm
c. 24 cm
b. 6 cm
d. −12 cm

5. The inability of a spherical lens to focus all parallel rays to a single point is called _____.

a. spherical aberration
c. virtual image formation
b. chromatic aberration
d. lens dispersion

6. The bending of different wavelengths of light as they pass through a lens is called _____.

a. spherical aberration
c. virtual image formation
b. chromatic aberration
d. prismatic aberration

7. An achromatic lens reduces chromatic aberration by using _____.

a. only one color of light

b. two lenses with different indices of refraction

c. both lenses and mirrors

d. a lens shaped like a prism

Section 18.3 Applications of Lenses

In your textbook, read about lenses in eyes on pages 500–501.

Answer the following questions. Use complete sentences.

1. What is the function of the lens in the eye?

2. What is nearsightedness and how is it corrected?

3. What is farsightedness and how is it corrected?

4. How does the lens change shape? What is this process called?

5. How does a convex lens correct vision?

Date ____________ Period ____________ Name ______________________

CHAPTER 18

Section 18-1 Quiz

1. Give the equation for Snell's law of refraction and explain what it means.

____

____

____

2. How is the index of refraction of a medium related to the speed of light?

____

____

____

3. What is the critical angle? How is it related to total internal reflection?

____

____

____

4. A beam of light passes from ethanol ($n = 1.36$) into diamond ($n = 2.42$) at an angle of $42°$. What is the angle of refraction?

5. What is the speed of light in crown glass ($n = 1.52$)?

6. What is the critical angle for light passing from flint glass ($n = 1.62$) into water ($n = 1.33$)?

Date ____________ Period ____________ Name ______________________

CHAPTER 18

Section 18-2 Quiz

1. What types of images can a convex lens produce, and under what conditions is each one produced?

____

____

____

____

____

____

2. What type of image does a concave lens produce?

____

____

3. What is the difference between spherical aberration and chromatic aberration?

____

____

____

4. A candle 2 m from a spherical lens produces an image that is 0.5 m from the lens and is inverted. What is the focal length of the lens?

5. If the candle in question 4 is 4 cm tall and the image is 8 cm tall, what is the magnification of the lens?

Date ____________ Period ____________ Name ________________________

CHAPTER 18

Section 18-3 Quiz

1. How does the eye focus images?

2. What causes nearsightedness and farsightedness?

3. How does a refracting telescope produce an image?

4. How are binoculars similar to telescopes? How are they different?

5. How are microscopes similar to telescopes? How are they different?

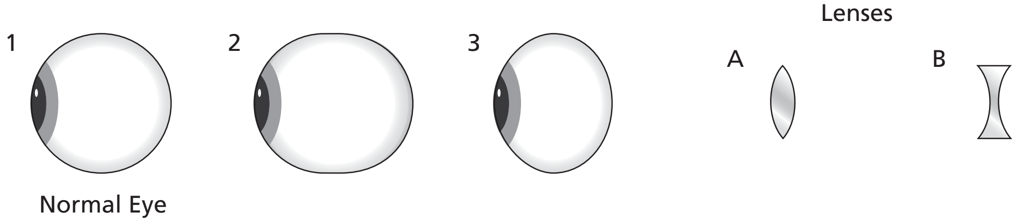
Date ______ Period ______ Name ______

CHAPTER 18

Reinforcement

Correcting Vision

The drawings below show the anatomy of the eye in both normal and abnormal configurations. In addition, two lenses are shown. Study the drawings and then answer the questions.



1. Does eye 2 have a problem? If so, what is it?

2. Does eye 3 have a problem? If so, what is it?

3. What would be the result of placing lens A in front of eye 1?

4. What would be the result of placing lens B in front of eye 1?

5. What would be the result of placing lens A in front of eye 2?

6. What would be the result of placing lens B in front of eye 2?

Date ______________ Period ______________ Name ______________________

CHAPTER 18

Enrichment

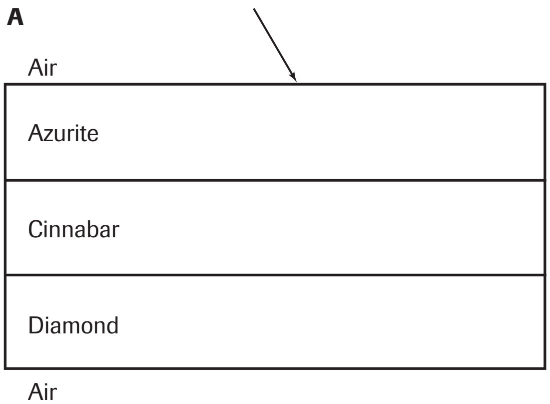
Minerals and Refraction

Table 1 shows the indices of refraction of various minerals. The drawings represent layers of minerals with parallel boundaries. Complete each drawing by extending each light ray to show how it behaves as it moves through each mineral and then into air. Begin with a 40.0° angle of incidence, as shown. Show your calculations in the space below each drawing.

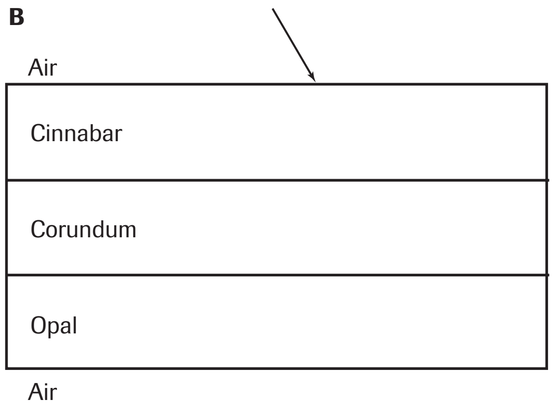
Table 1

Mineral	Index of refraction
Almandite (garnet)	1.83
Azurite	1.76
Beryl	1.57
Calcite	1.66
Cinnabar	2.81
Corundum (ruby, sapphire)	1.77
Diamond	2.42
Opal	1.44
Zircon	1.92

A



B



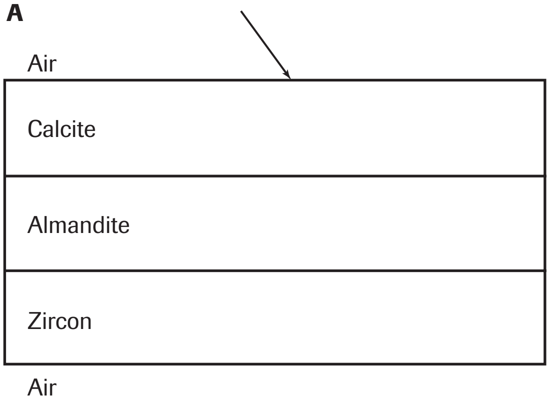
1. What pattern did you see in how the light ray bent with respect to the normal?

2. In which mineral is the speed of light the highest? Explain your answer.

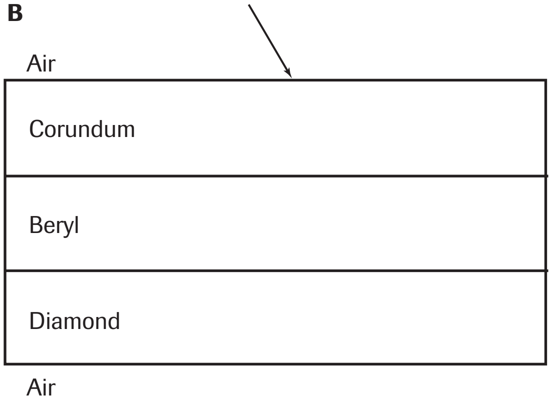
3. In which mineral is the speed of light the lowest? Explain your answer.

4. For each diagram below, predict which way the light ray will bend. You do not have to predict precise angles. Show the light rays and describe how the light bends in terms of position relative to the normal.

A



B



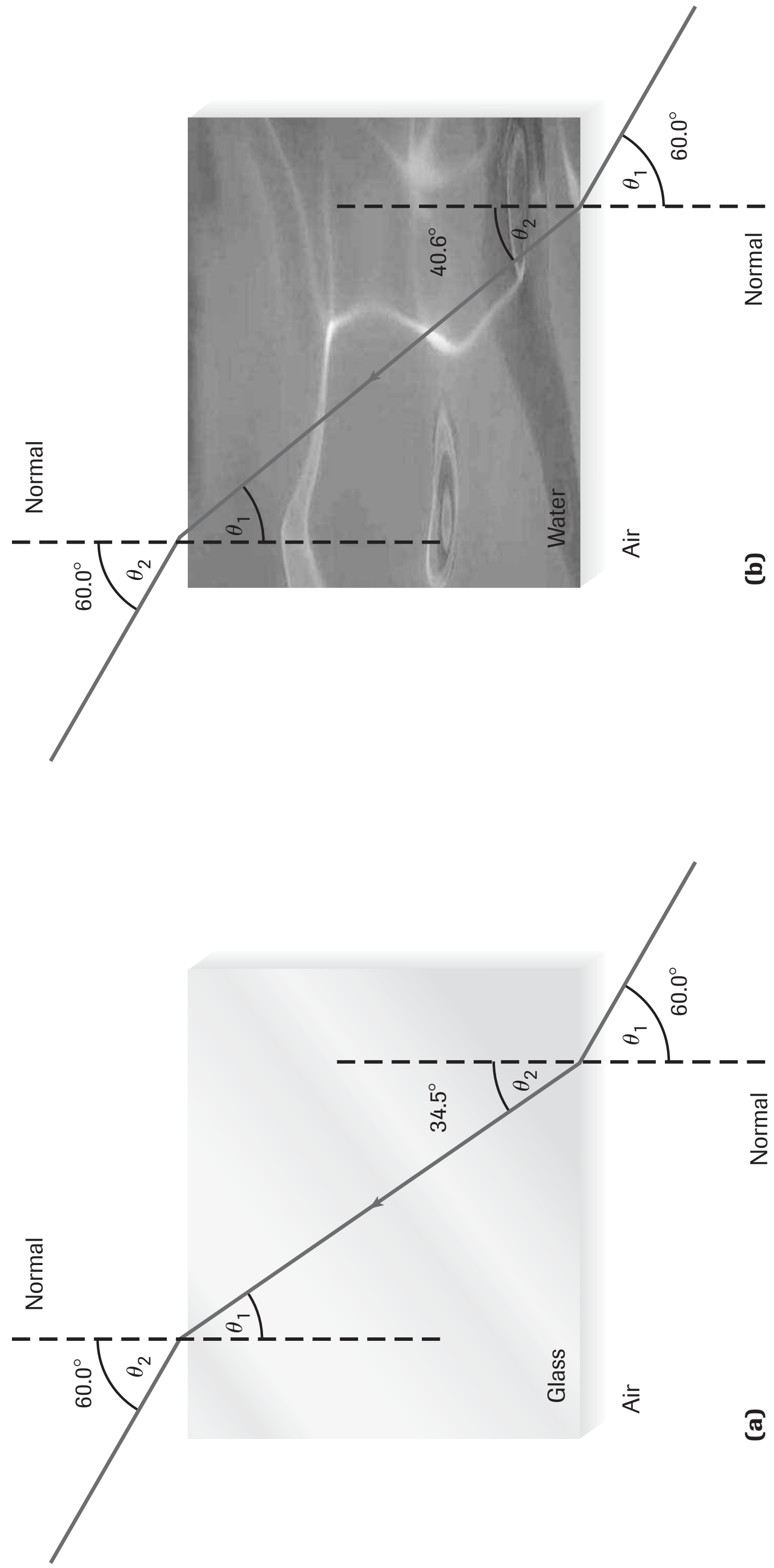
5. Look at all four diagrams on this page and the previous one. At which boundary did light bend the most? Explain why this happened.

6. Look at all four diagrams on this page and the previous one. At which boundary did light bend the least? Explain why this happened.

7. Under what circumstances would light bend neither toward nor away from the normal?

Transparency 18-1

Index of Refraction



Date ____________ Period ____________ Name ______________________

18 Transparency 18-1 Worksheet

Index of Refraction

1. What do the red arrows represent?

---

2. What is the angle of incidence for light entering the glass?

---

3. What is the angle of refraction for light entering the glass?

---

4. What is the value of θ_i for light leaving the glass?

---

5. What is the value of θ_i for light entering the water?

---

6. Based on the figures, which medium would you expect to have a greater index of refraction: glass or water? Why?

---

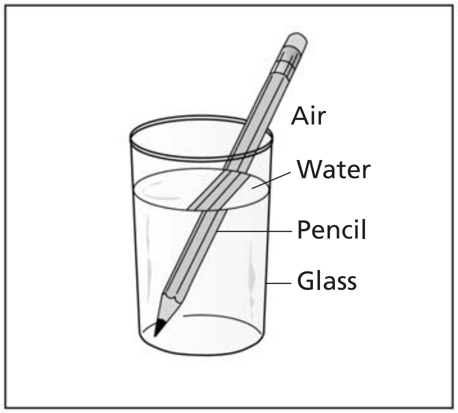
7. Calculate the index of refraction for the glass.

8. Calculate the index of refraction for the water.

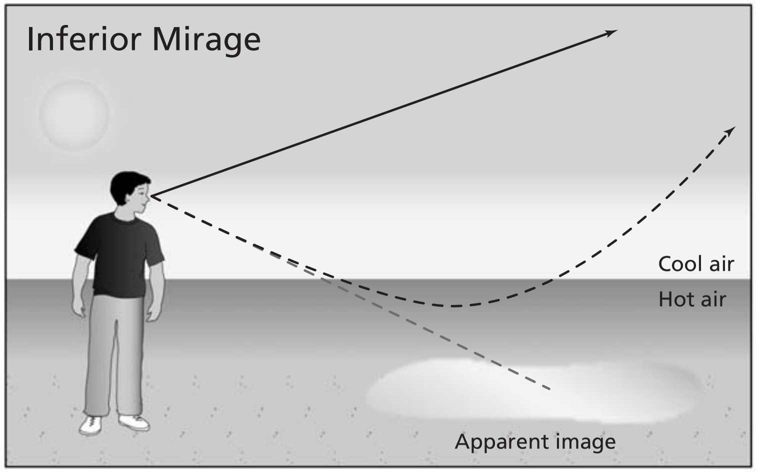
9. Through which of the two media—glass or water—does light travel faster?

CHAPTER 18 Transparency 18-2

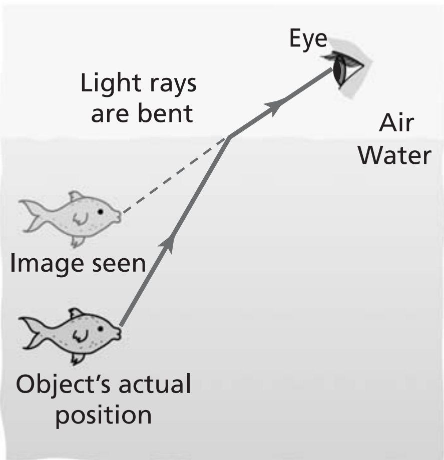
Refraction of Light and Illusions



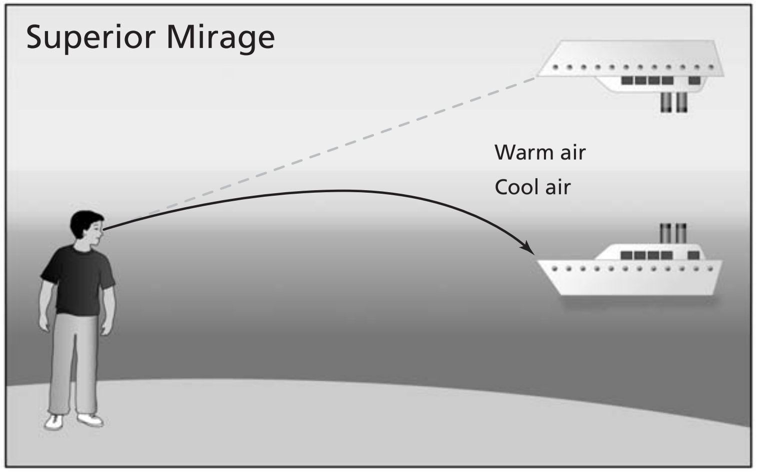
Broken Pencil Trick



Note: Scale is greatly exaggerated.



How Deep Is It Really?



Note: Scale is greatly exaggerated.

18 Transparency 18-2 Worksheet

Refraction of Light and Illusions

1. In the drawing of the inferior mirage, what does the person think that he sees? What does he actually see?

2. What causes the inferior mirage effect?

3. In the drawing of the superior mirage, what does the person think that he sees? What does he actually see?

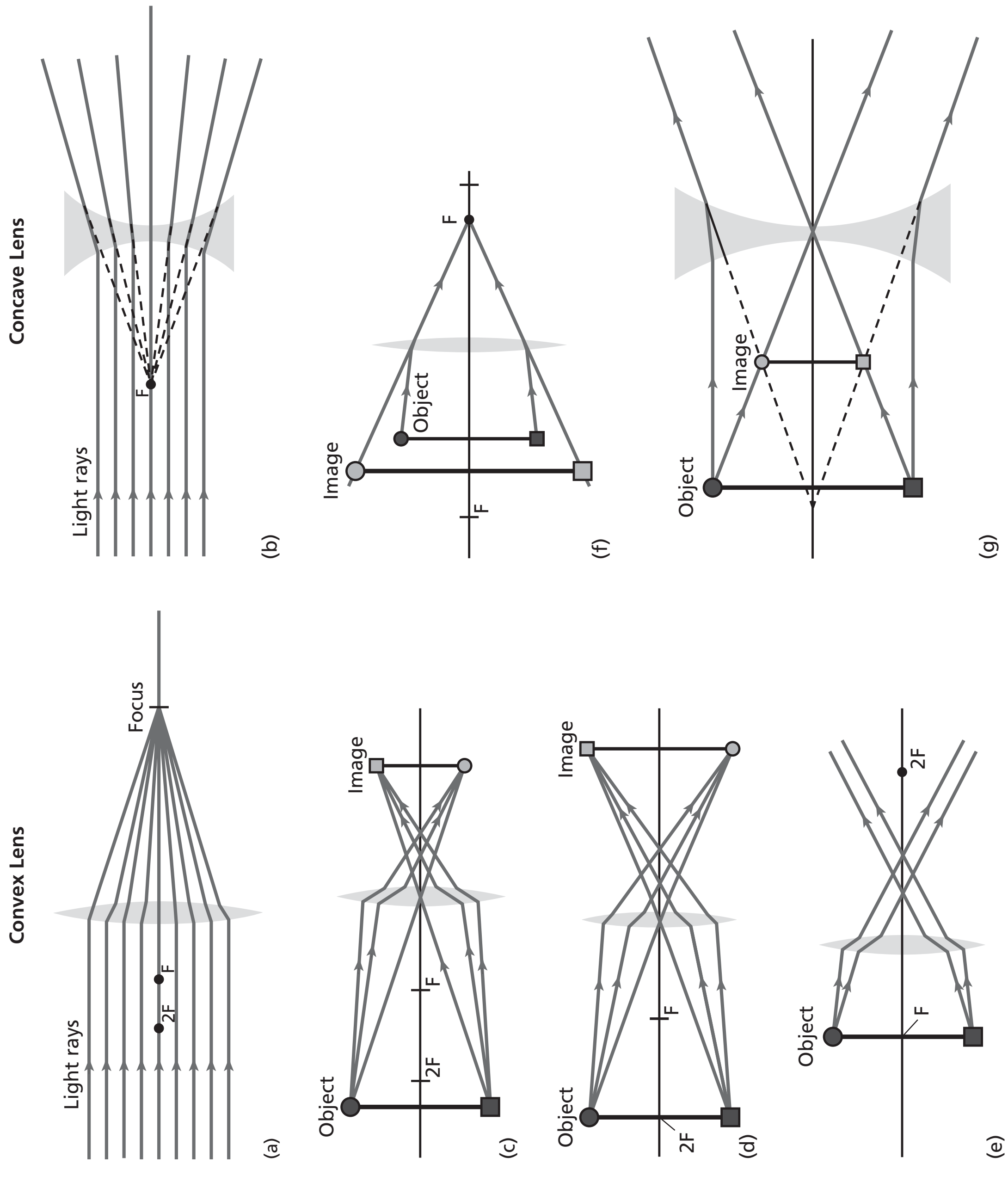
4. What causes the superior mirage effect?

5. In the drawing of the pencil in water, why does the pencil appear to be broken?

6. In the drawing of the fish in water, why does the fish appear to be closer to the surface than it really is?

Transparency 18-3

Images Formation by Curved Lenses



Date ____________ Period ____________ Name ______________________

18 Transparency 18-3 Worksheet

Images Formation by Curved Lenses

1. What type of lens is shown in Figure a? In Figure b?

2. What does F represent?

3. Where is light from a very distant object focused by a convex lens?

4. As the object moves from very far away to very close to F, how does the image produced by a convex lens change?

5. What might you do to see the images produced by a convex lens?

6. When does an object's size equal the image size for a convex lens?

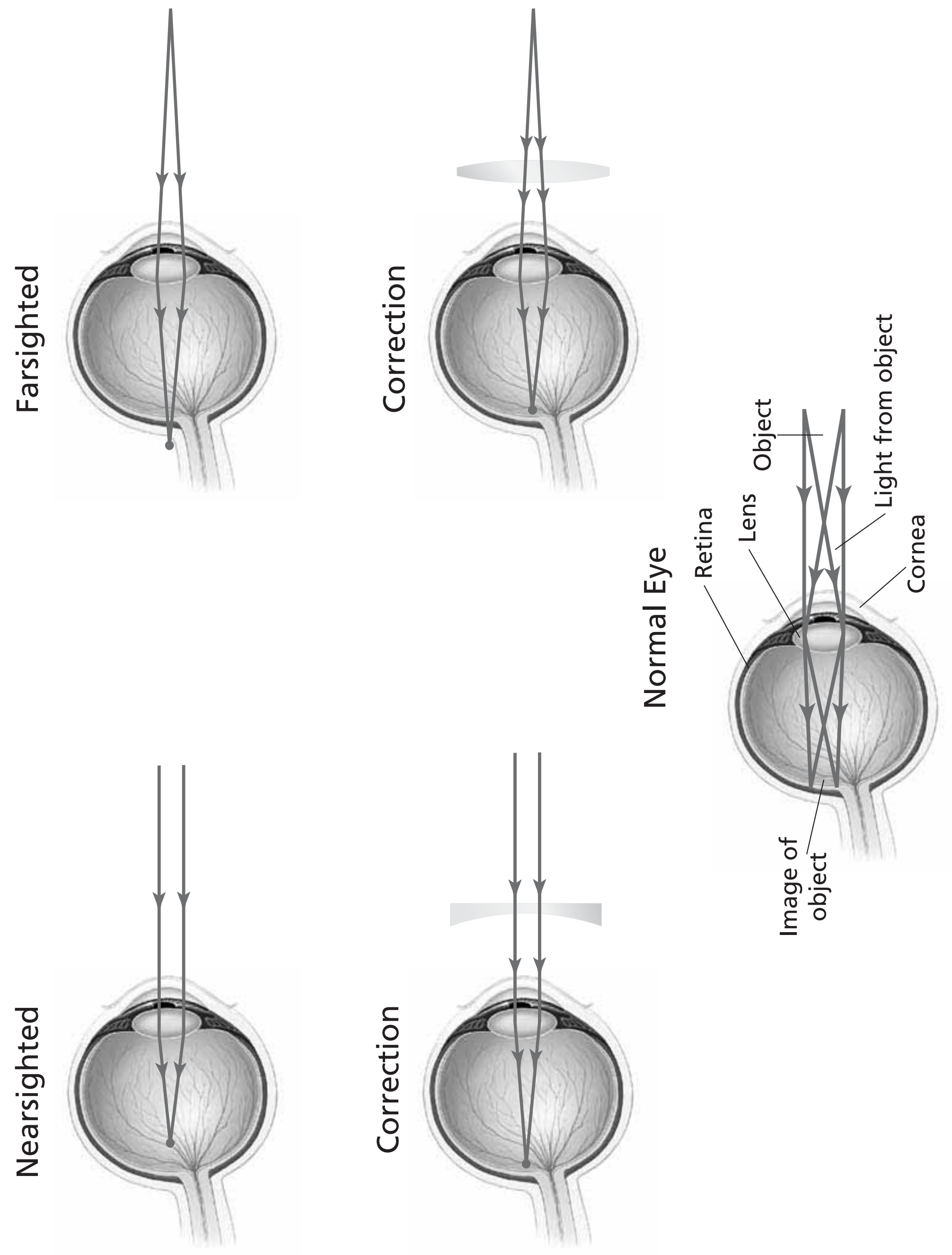
7. What happens to the image when the object is between F and a convex lens?

8. What effect does a concave lens have on light rays?

9. What type of image is formed by a concave lens?

Transparency 18-4

Nearsightedness, Farsightedness, and Lenses



Date ____________ Period ____________ Name ______________________

18 Transparency 18-4 Worksheet

Nearsightedness, Farsightedness, and Lenses

1. What happens to light that enters a normal eye?

2. The diagram on the left illustrates nearsightedness. From what direction is the light coming? Where is the lens of the eye? Where is the retina?

3. What happens to light entering the eye when a person is nearsighted?

4. Explain why nearsightedness occurs in terms of the structure of the affected eye.

5. What kind of lens is used to correct nearsightedness? Is such a lens a converging or a diverging lens? How does the use of such a lens affect the vision of a nearsighted person?

6. The diagram on the right illustrates farsightedness. What happens to light entering the eye when a person is farsighted?

7. Explain why farsightedness occurs in terms of the structure of the affected eye.

8. What kind of lens is used to correct farsightedness? Is such a lens a converging or diverging lens? How does the use of such a lens affect the vision of a farsighted person?

CHAPTER 18

Chapter Assessment

Refraction and Lenses

Understanding Physics Concepts

Circle the letter of the choice that best completes the statement or answers the question.

1. Compared to its speed in air, the speed of light in glass is _____.

a. the same
b. faster
c. slower
d. not measurable

2. Which of the following has the highest index of refraction?

a. a vacuum
b. air
c. diamond
d. crown glass

3. For most practical purposes, the index of refraction of air is _____.

a. 0
b. 1.00
c. infinite
d. equal to that of the other medium involved

4. The wavelength of light in a given material equals _____.

a. the speed of light in the material times frequency
b. frequency times the speed of light in the material
c. the speed of light in the material divided by frequency
d. frequency divided by the speed of light in the material

5. Which expression equals the index of refraction of a given medium?

a. $\frac{c}{v_{medium}}$
b. $\frac{v_{medium}}{c}$
c. $c - v_{medium}$
d. $v_{medium} - c$

6. Refraction occurs when _____.

a. light travels through the boundary of two media that have different indices of refraction
b. light strikes the boundary of two media that have the same indices of refraction
c. the angle of incidence equals zero
d. the angle of reflection equals zero

7. When light travels from one medium into a medium with a lower index of refraction, _____.

a. the speed of light increases
b. the angle of refraction is smaller than the angle of incidence
c. the refracted light bends toward the normal
d. the angle of incidence equals the angle of refraction

8. The index of refraction of the transparent mineral beryl is approximately 1.6. Transparent quartz has an index of 1.54. Diamond has an index of 2.42. Based on these facts, which statement is true?

a. All three minerals bend light to the same extent.

b. Quartz bends light more than beryl does.

c. Beryl bends light more than quartz does.

d. Both beryl and quartz bend light more than diamond does.

9. The image formed of an object when the object is more than twice the focal length from a convex lens is _____.

a. real and smaller than the object

b. real and larger than the object

c. virtual and smaller than the object

d. virtual and larger than the object

For each statement below, write true *or rewrite the italicized part to make the statement true.*

10. ____________________ *Chromatic* aberration can be reduced by joining together a convex lens and a concave lens.

11. ____________________ Concave lenses have *positive* focal lengths.

12. ____________________ The higher the index of refraction is, the *faster* is the speed of light in the substance.

13. ____________________ The index of refraction of a material can be never be *less than* 1.00.

14. ____________________ A vacuum has an index of refraction that is *larger* than that of any substance.

15. ____________________ In a glass prism, the index of refraction for violet light is *smaller* than for red light.

16. ____________________ A rainbow is a spectrum formed when sunlight is *dispersed by water droplets* in the atmosphere.

17. ____________________ The sunlight that falls on a water droplet is *reflected*.

18. ____________________ Each droplet produces a *single wavelength of the* spectrum of visible light.

19. ____________________ An observer positioned between the Sun and the rain sees *only a certain wavelength of* light from each droplet.

20. ____________________ The wavelength depends on the relative position of the Sun, *the rainbow*, and the water droplet.

21. ____________________ Because *there are so many water droplets* in the sky, an observer is able to see a complete spectrum.

22. ____________________ Consider white light directed through and dispersed by a prism: If color A is refracted more than color B, then color A must have a *lower* frequency than color B and the speed of light of color A through the prism must be *less than* the speed of light of color B.

Thinking Critically

Answer the following questions. Use complete sentences.

1. Explain the relationship between the sine of the angle of incidence and the sine of the angle of refraction of light rays traveling from a vacuum into a medium.

2. What is the relationship between total internal reflection and the critical angle?

3. When light passes from one medium into another that has a lower index of refraction, how does the angle of refraction compare to the angle of incidence? What happens as the angle of incidence is increased?

4. Contrast convex and concave lenses.

5. Contrast the image formed by a convex lens when an object is located more than twice the focal length from the lens with the image formed when the object is between the lens and the focal point.

Answer the following questions. Show your calculations.

6. Light traveling through air reaches quartz at an angle of incidence of 35°. The index of refraction of quartz is 1.54. At what angle of refraction does the light travel into the quartz?

7. Light enters a substance from air at an angle of incidence of 55°. The light is refracted inside the substance to an angle of refraction of 35°. What is the index of refraction of the substance?

8. Diamond has an index of refraction of 2.42. When it is immersed in water, which has an index of 1.33, and light in the water enters the diamond at a 53° angle of incidence, what is the angle of refraction inside the diamond?

Applying Physics Knowledge

Answer the following questions. Show your calculations.

1. The index of refraction of halite, or rock salt, is 1.54. What is the speed of light in that mineral?

2. An object is 5.00 cm from a convex lens that has a focal length of 6.00 cm. Locate the image and determine whether it is real or virtual.

3. What is the focal length of a concave lens that forms an image with a d_i value of −10.0 cm when an object is 35.0 cm from the lens?

4. Flint glass has an index of refraction of 1.57 for red light and 1.59 for violet light. If incident white light moving through the air reaches the glass at an angle of incidence of 65.0°, what will the angle be between the red and violet components of the refracted light?

5. Suppose that the flint glass from problem 4 is again used to refract white light. The source of the light is adjusted so that the light reaches the glass at an angle of incidence of 60.0°. Does this new angle of incidence change the amount of dispersion between the red and violet light?

6. Light in a tub of water makes an angle of incidence of 52.0° as it reaches the surface from below. The index of refraction of air is 1.00 and that of water is 1.33.

a. Show that the light undergoes total internal reflection.

b. What is the value of the angle of reflection for the reflected ray?

Reproducible Pages Contents

Interference and Defraction

Date ______________ Period ______________ Name ______________________

CHAPTER 19

Mini Lab Worksheet

Retinal Projection Screen

Did you know that you can use the retina of your eyeball as a screen? ***CAUTION: Do not do the following with a laser or the Sun.***

1. Plug in and turn on an incandescent lamp with a straight filament. Stand about 2 m from the lamp.
2. Hold a diffraction grating in front of your eye so the color spectra are oriented horizontally.
3. **Observe** the color spectra patterns and draw your observations using your colored pencils and a sketch.

Analyze and Conclude

4. Which color is closest to the central bright line (the light filament)?

____

5. Which color is farthest from the central bright line?

____

6. How many spectra are you able to see on either side of the light?

____

7. **Interpret Data** Are your observations consistent with the equation for the wavelength from a diffraction grating?

____

____

Date ______________ Period ______________ Name ______________________

CHAPTER 19

Physics Lab Worksheet

Materials

- ■ **Use laser protective eyewear approved by ANSI.**
- ■ **Never look directly into the light of a laser.**
- laser pointer or laser to be tested
- double-slit plate
- laser pointer or laser of known wavelength
- clothes pin to hold a laser pointer
- clay ball to hold the double-slit plate
- meterstick

Double-Slit Interference of Light

Light sometimes behaves as a wave. As coherent light strikes a pair of slits that are close together, the light passing through the slits will create a pattern of constructive and destructive interference on a screen. In this investigation you will develop a procedure and measure the wavelength of a monochromatic light source using two slits.

Question

How can a double-slit interference pattern of light be used to measure the light's wavelength?

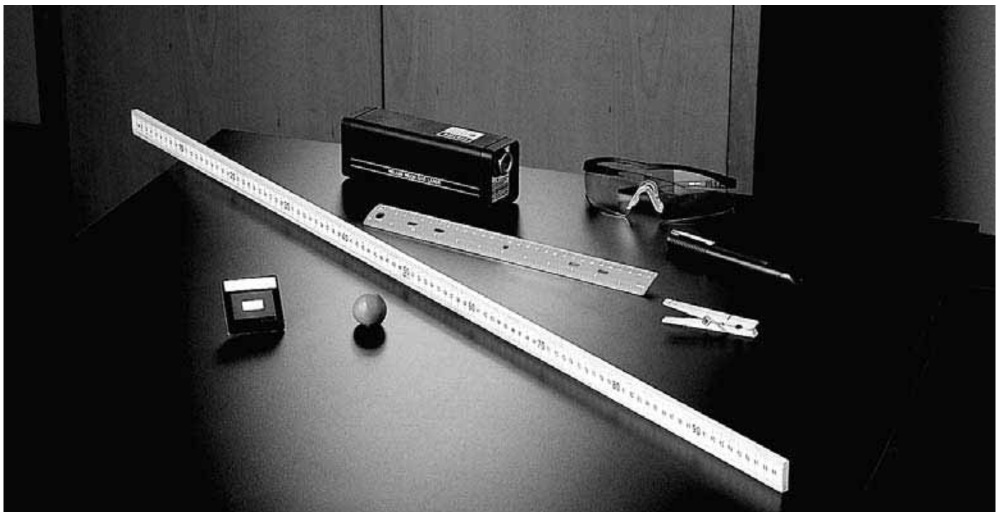
Objectives

- ■ **Observe** a double-slit interference pattern of monochromatic light.
- ■ **Calculate** the wavelength of light using a double-slit interference pattern.

Procedure

1. Determine which equation applies to double-slit interference.

2. Use a double slit of known slit-separation distance, *d*, or develop a method to determine *d*.



19 Physics Lab Worksheet

Data Table

Source	Color	Accepted λ (m)	*d* (m)	*m*	*x* (m)	*L* (m)
				1		
				2		
				3		
				4		
				5		

3. Sketch how light passes through a double-slit to help you determine how x and L can be measured.

4. Using your sketch from step 3 and the list of possible materials provided in this lab, design the lab setup and write a procedure for performing the experiment.

5. Determine the values of m that would be invalid for the equation.

6. ***CAUTION: Looking directly into laser light could damage your eyes.***

7. Check with your teacher for approval before you implement your design.

8. Perform your experiment. Write your data in the table on this page.

Analyze

1. **Experiment** Adjust the distance of your slits from the screen. Is there a distance that allows you to collect the most data with the best precision?

2. **Calculate** the wavelength, λ, of your light source using M and measurements of x, d, and L.

3. **Error Analysis** Compare your calculated wavelength to the accepted value by determining the percentage of error.

Conclude and Apply

1. **Conclude** whether your procedure enabled you to use a double-slit interference pattern to measure the wavelength of light. Explain.

2. **Estimate** the results you would get if you used a plate with a smaller slit separation distance, d, and performed the experiment exactly the same.

3. **Infer** how your observations would change if you used green light with the same double-slit plate and screen distance. What would you observe?

Going Further

1. **Use a scientific explanation** to describe why the double-slit interference pattern dims, brightens, and dims again as distance from the center of the pattern increases.

2. **Describe** several things you could do in the future to reduce systematic error in your experiment.

3. **Evaluate** the measuring equipment you used and determine which equipment limited you the most on the precision of your calculations and which equipment gave you more precision than you needed, if any.

4. **Lab Techniques** What might be done to an experimental setup to use white light from a normal lightbulb to produce a double-slit interference pattern?

Real-World Physics

1. When white light shines through slits in a screen door, why is a pattern not visible in the shadow on a wall?

2. Would things look different if all of the light that illuminated the world was coherent? Explain.

Physics Online

To find out more about interference patterns, visit the Web site: **physicspp.com**

Date ____________ Period ____________ Name ______________________

CHAPTER 19

Study Guide

Interference and Diffraction

Vocabulary Review

Write the term that correctly completes the statement. Use each term once.

diffraction grating
diffraction pattern
interference fringes
Rayleigh criterion
thin-film interference

1. ____________________ _____ results in a spectrum of colors caused by constructive and destructive interference of reflected light waves.

2. ____________________ A(n) _____ is a device made up of many single slits that diffract light and form a pattern that results from the overlapping of single-slit diffraction patterns.

3. ____________________ A(n) _____ is a pattern that results from constructive and destructive interference of Huygens' wavelets.

4. ____________________ If the central bright spot of a star's image falls on the first dark ring of a second star's image, the two images are at the limit of resolution. This statement is the _____.

5. ____________________ A pattern of bright and dark bands called _____ is produced by coherent light passing through two slits and overlapping on a screen.

Use the terms **incoherent light, coherent light,** *and* **monochromatic light** *to complete the following concept map.*

Types of Light

6. ______________	**7.** ______________	**8.** ______________
Light from two or more wave sources that superimposes to produce smooth wave fronts	Light of only one wavelength	Light that has unsynchronized wave fronts and produces no regular patterns

Section 19.1 Interference

In your textbook, read about the interference of coherent light on pages 516–519.

Circle the letter of the choice that best completes the statement or answers the question.

1. How many slits were present in the experiment that Young used to observe interference fringes?

a. one **c.** three

b. two **d.** four

2. Interference fringes result from ______.

a. constructive and destructive interference **c.** refraction

b. particle interactions **d.** wavelet creation

3. A monochromatic light source emits light of ______.

a. all wavelengths **c.** different wavelengths that interfere constructively

b. one wavelength **d.** different wavelengths that interfere destructively

4. Wave crests that reach the same points at the same times are said to be ______.

a. diffractive **c.** out of phase

b. in phase **d.** noncoherent

5. Where two wave crests overlap, ______.

a. a bright band is created **c.** a dark band is created

b. a colored band is created **d.** diffraction occurs

6. Where a wave crest and a wave trough overlap, ______.

a. a bright band is created **c.** a dark band is created

b. a colored band is created **d.** diffraction occurs

7. In a two-slit experiment that uses monochromatic light, a ______ appears at the center of the screen.

a. bright band **c.** dark band

b. complete spectrum **d.** two-colored band

8. In a double-slit experiment that uses white light, a ______ appears at the center of the screen.

a. white band **c.** dark band

b. color spectrum **d.** two-colored band

9. In a double-slit experiment that uses white light, ______ appear away from the center of the screen.

a. bright bands only
b. colored spectra
c. dark bands only
d. monochromatic bands

10. A student performed an experiment to measure wavelength by using coherent, monochromatic light and two slits. On the screen, the bright bands appear when the difference between the length of the path from one slit to the band and the length of the path from the other slit to the band is ______.

a. equal to a multiple of λ
b. equal to λ
c. equal to the distance between the slits
d. equal to $\frac{\lambda}{2}$

11. The equation used to calculate wavelength from a double-slit experiment is ______.

a. $\lambda = \frac{Lx}{d}$
b. $\lambda = \frac{Ld}{x}$
c. $\lambda = xdL$
d. $\lambda = \frac{xd}{L}$

12. Which of the following quantities is NOT needed to calculate wavelength from a double-slit experiment when using the small angle simplification?

a. the distance between the slits
b. the distance from the slits to the screen
c. the distance between the center bright band and the first bright band
d. the angle formed by the paths from the slits to the center band and the first bright band

In your textbook, read about measuring wavelength with double-slit diffraction on page 518.
For each description on the left, write the matching term on the right.

______	**13.** distance between the central bright band and the first-order band	d
______	**14.** distance between the slits and the screen	L
______	**15.** location of the central bright band	P_1
______	**16.** location of the first-order band	P_0
______	**17.** separation of two slits	x
______	**18.** wavelength	λ

In your textbook, read about thin-film interference on pages 520–523.

For each statement below, write* true*, or rewrite the italicized part to make the statement true.

19. ______________________ A soap bubble is an example of a *thin film*.

20. ______________________ The colors that you see in a film of oil on a puddle are caused by *the absorption of colors in a pigment*.

21. ______________________ Thin-film interference is caused *only by constructive* interference of light waves due to reflection in a thin film.

22. ______________________ In thin-film interference, the source of the light that is reflecting off the thin film can be *coherent or incoherent*.

23. ______________________ The reflected color in thin-film interference depends on *only the film thickness*.

In your textbook, review the example and practice problems in Section 19-1.

Answer the following questions. Show your calculations.

24. A double-slit experiment is conducted to find the wavelength of a certain monochromatic light. The slit is 55.0 cm from the screen, and the slits are 0.0200 mm apart. The experiment showed that the central bright band and the first-order bright band are 18.6 mm apart. Find the wavelength of the light in nm.

25. A thin film of oil on water produces a blue color, in addition to other colors. What would be the thinnest film of oil that would produce a blue color that has a wavelength of 442 nm? The refractive index of the oil (n_{oil}) is 1.45, and that of water (n_{water}) is 1.33.

Section 19.2 Diffraction

In your textbook, read about single-slit diffraction on pages 524–526.

For each statement below, write* true*, or rewrite the italicized part to make the statement true.

1. ______________________ When monochromatic light passes through a slit, it is diffracted when the wavelength of the light is *longer* than the width of the slit.

2. ______________________ The pattern produced by single-slit diffraction is a *wide bright central band with dimmer, narrower bands* on either side.

3. ______________________ Bright bands are caused by constructive interference of *Young's wavelets*.

4. ______________________ Dark bands in a pattern can be calculated by multiplying a whole number by the wavelength *multiplied by the width of the slit divided by the distance to the screen*.

In your textbook, read about diffraction gratings on pages 527–530.

Write the term that correctly completes the statement. Use each term once.

θ	**broad**	**holographic**	**transmission**
$\frac{\lambda}{d}$	**colors**	**diffraction**	**wavelengths**
angle	**diffract**	**narrow**	
	grating	**reflection**	

The many parallel slits on a diffraction grating (**5**) ______________ light, and a(n) (**6**) ______________ pattern forms. The pattern consists of (**7**) ______________ bright lines and (**8**) ______________ dark bands. When white light is used, the pattern is made up of many (**9**) ______________. When a diffraction grating is made on transparent glass, it is called a(n) (**10**) ______________ grating. A(n) (**11**) ______________ grating is formed using a reflective surface. The brightest patterns that are made using lasers and mirrors are called (**12**) ______________ diffraction gratings. An instrument that uses diffraction gratings to measure (**13**) ______________ is called a(n) (**14**) ______________ spectroscope. Wavelength can be found by measuring the (**15**) ______________ between the central bright line and the first bright line, which is represented by the variable (**16**) ______________. The sine of this angle equals (**17**) ______________.

In your textbook, read about the resolving power of lenses on pages 530–531.
Circle the letter of the choice that best completes the statement or answers the question.

18. The aperture in a telescope or microscope _____ light that passes through it.

a. diffracts
c. reflects
b. angles
d. refracts

19. The Rayleigh criterion states that if the bright spot of one star's image falls on _____ of another star's image, the two images are at the limit of resolution.

a. any dark ring
c. the first dark ring
b. the bright spot
d. the shadow

20. The Rayleigh criterion cannot be used when _____ is used to make observations.

a. a telescope
c. a microscope
b. the human eye
d. a camera

21. If the cones in the human eye were further apart, they would not be able to _____.

a. resolve all possible detail
c. ignore details of the diffraction pattern
b. see colors
d. distinguish light and dark

In your textbook, review the example and practice problems in Section 19-2.
Answer the following questions. Show your calculations.

22. Monochromatic violet light with a wavelength of 412 nm falls on a single slit that has a width of 0.038 mm. The slit is located 85 cm from a screen. How wide, in mm, is the central band in the pattern that is produced?

23. Green light of wavelength 524 nm shines through a diffraction grating. The resulting pattern on a screen 85.0 cm away shows a difference of 94.0 cm between the central bright line and the one next to it. What is the spacing between the slits in the grating in nm?

Date ________ Period ________ Name ________________

CHAPTER 19

Section 19-1 Quiz

1. Compare and contrast monochromatic, incoherent, and coherent light.

____

____

____

____

2. Explain how coherent light falling on two slits produces an interference pattern. Include the difference between constructive and destructive interference.

____

____

____

____

____

3. Two slits are 0.0158 mm apart. Light is shined through the slits, and an interference pattern forms on a screen that is located 0.730 m away. The distance between the central bright band and the first-order bright band is 21.4 mm. What is the wavelength of the light?

4. The colors produced on a soap film in air include red. What would be the thinnest film of soap solution in nm that would produce a red color that has a wavelength of 633 nm? The index of refraction of soap solution is $n_{soap} = 1.33$.

Date ____________ Period ____________ Name ______________________

CHAPTER 19

Section 19-2 Quiz

1. Discuss the differences in the patterns produced by single-slit and double-slit setups.

____

____

____

____

____

2. Monochromatic blue light with a wavelength of 483 nm falls on a single slit and produces a pattern with a central bright band that is 21 mm wide. The slit is located 94 cm from a screen. How wide is the slit?

3. Explain the operation and purpose of a grating spectroscope.

____

____

____

____

____

4. What is the limit of resolution for a telescope lens with a diameter of 120 cm when it observes a star at a distance of 4 light years? Use the wavelength of $\lambda = 550$ nm in your calculations.

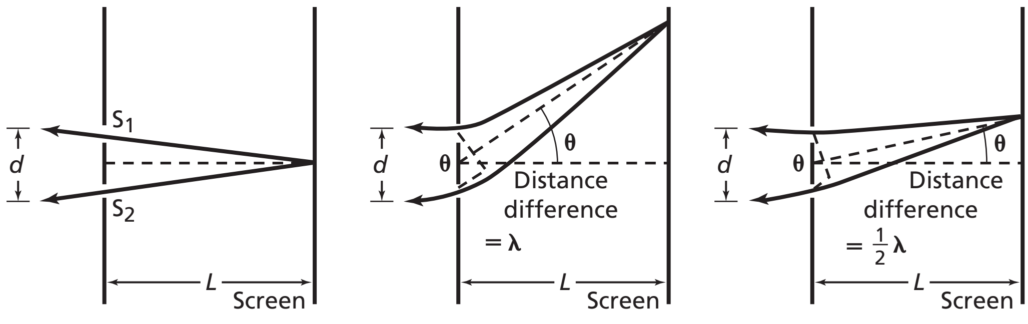
Date ____________ Period ____________ Name ________________________

CHAPTER 19

Reinforcement

Double-Slit Interference

In **Figures a, b,** and **c,** label the results on the screen as either a *dark band* or a *light band*. Below each figure, state whether the figure shows *constructive interference* or *destructive interference*.



(a) (b) (c)

Complete **Figure d** to show how the band just below the center band forms. Complete **Figure e** to show how the first bright band below the center band forms. Use the labels *bright band, dark band, constructive interference, destructive interference, d, extra distance* (and what it equals), and θ as needed.

(d) (e)

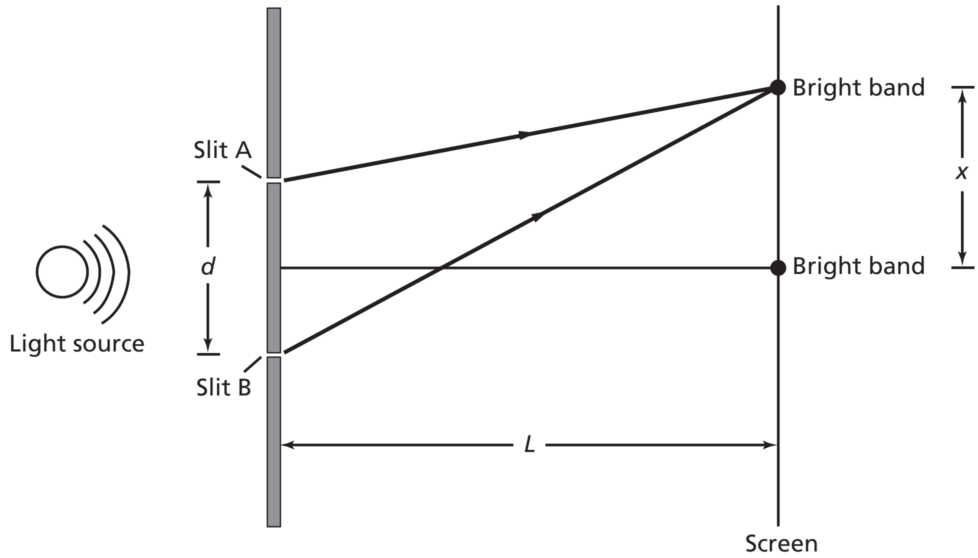
Date ______________ Period ______________ Name ______________________

CHAPTER 19

Enrichment

Determining Wavelength by Interference

Red light has a specific wavelength, as does blue light. Other colors of light also have different, unique wavelengths. The wavelength of a particular color of light can be determined by shining the light through a double-slit apparatus. This procedure produces a pattern of bright bands and dark bands on a screen. Measurements taken during such an experiment can be used to calculate the wavelength of the color of light that was shined through the slits.



1. How does the distance from Slit A to the center line on the screen compare to the distance from Slit B to the center line on the screen?

____

2. What causes the bright band to be produced on the center of the screen?

____

____

____

3. What type of band is next to the central bright band?

____

4. Why are the bands next to the central bright band present on the screen?

____

____

____

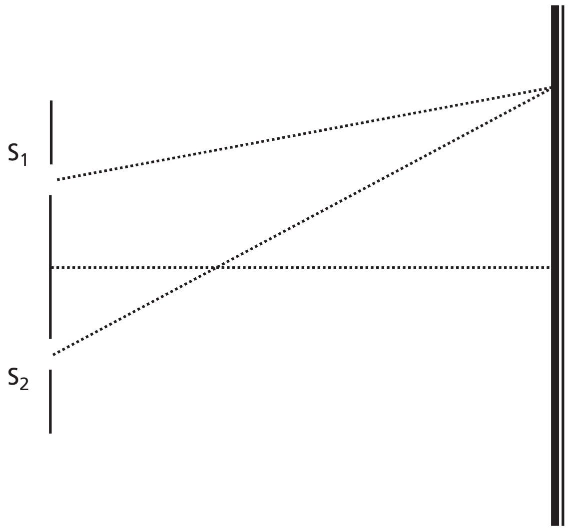
5. The figure on page 121 shows another bright band next to the central bright band on the screen. What can you conclude about the difference between the length of the path of the light from Slit A and the length of the path of the light from Slit B to this band?

____

____

____

6. List three measurements that must be made in order to calculate wavelength from a double-slit interference setup. Use the variables *d*, *L*, and *x* to label these distances on the diagram.



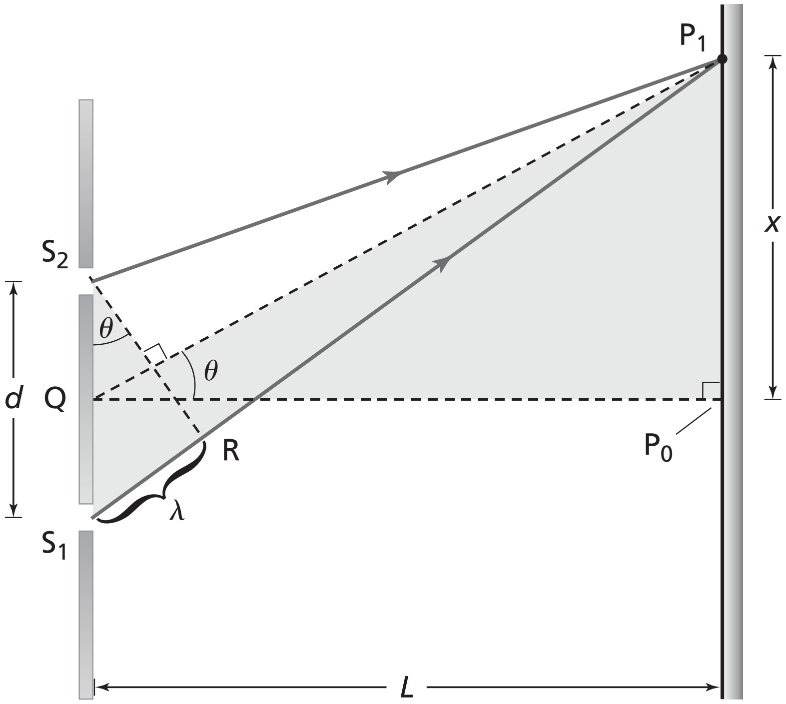
7. Write the equation that uses these variables to calculate the wavelength of light.

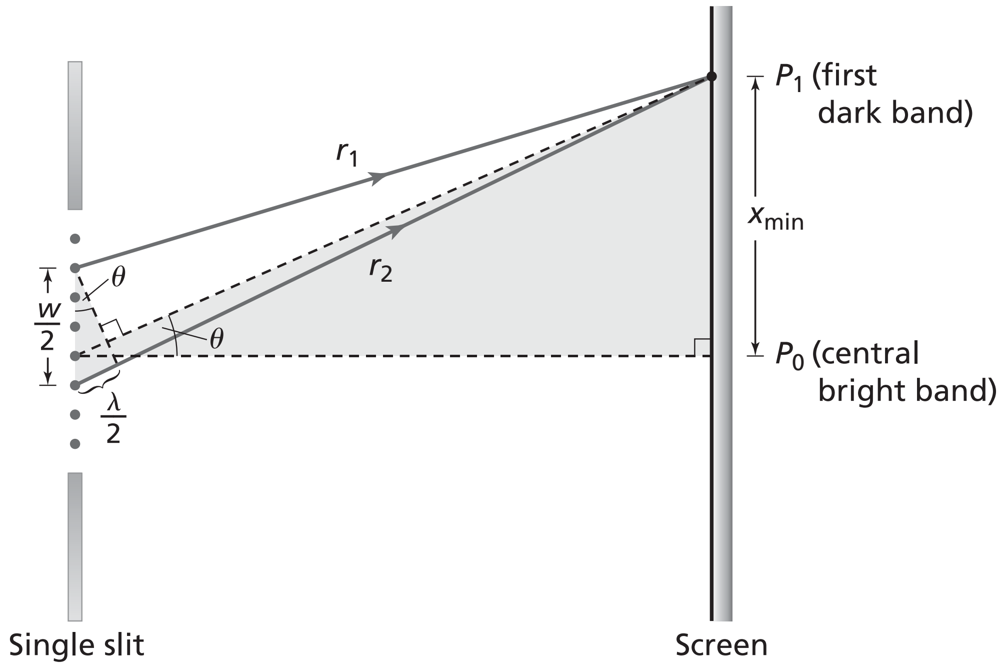
____

8. In the space below, write a process map that summarizes how you would determine wavelength by using double-slit interference. Use at least five steps in your events chain.

Transparency 19-1

Destructive and Constructive Interference





Date ____________ Period ____________ Name ______________________

19 Transparency 19-1 Worksheet

Destructive and Constructive Interference

1. What does P_1 represent?

2. How do the lengths of P_1S_1 and P_1S_2 compare?

3. What is the length of S_1R?

4. How can you determine the wavelength of light by using a double-slit interference pattern? What equation do you use?

5. Why is the central band bright in a single-slit setup?

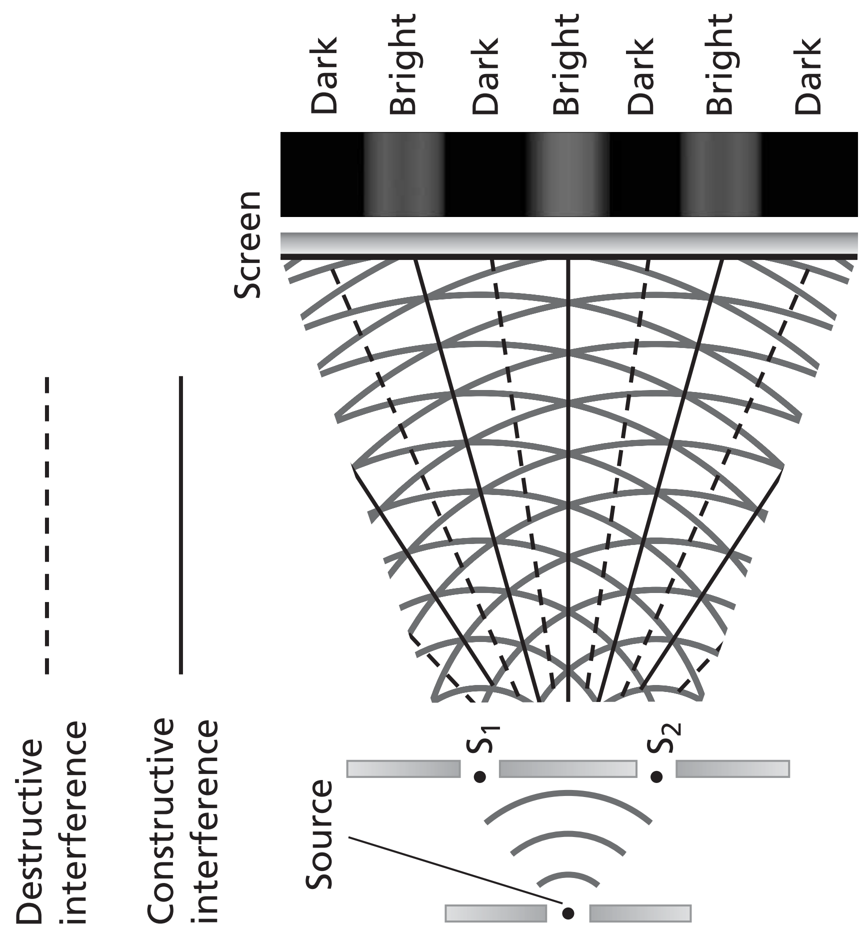
6. How is the width of the central band affected by the width of the single slit?

7. What equation relates x, L, w, and λ?

CHAPTER

19 Transparency 19-2

Double-Slit Wave Interference



Date ________________ Period ________________ Name ______________________________

19 Transparency 19-2 Worksheet

Double-Slit Wave Interference

1. What happens to light waves as they pass through the double slits?

2. What is the name given to the pattern of bright and dark bands that are formed?

3. What part of the illustration represents the crests of the light waves?

4. How are regions of destructive interference represented? Of constructive interference?

5. What parts of the illustration represent resulting waves that have amplitudes greater than those of the original waves? What parts represent resulting waves with amplitudes less than those of the original waves?

6. How many colors of light produced the pattern that is shown?

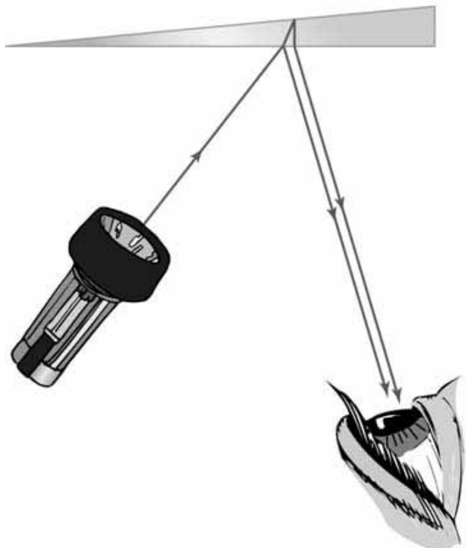
7. How would the illustration differ if the light source were white light?

8. What would the pattern look like if one of the slits were covered?

CHAPTER 19

Transparency 19-3

Thin-Film Interference



Date ____________ Period ____________ Name ________________________

19 Transparency 19-3 Worksheet

Thin-Film Interference

1. Each photograph shows a pattern that is an example of thin-film interference. What produces the spectrum of color in these photographs? Give an example for each one.

2. Consider the pattern in the photograph on the right. Why does it show different bands of color?

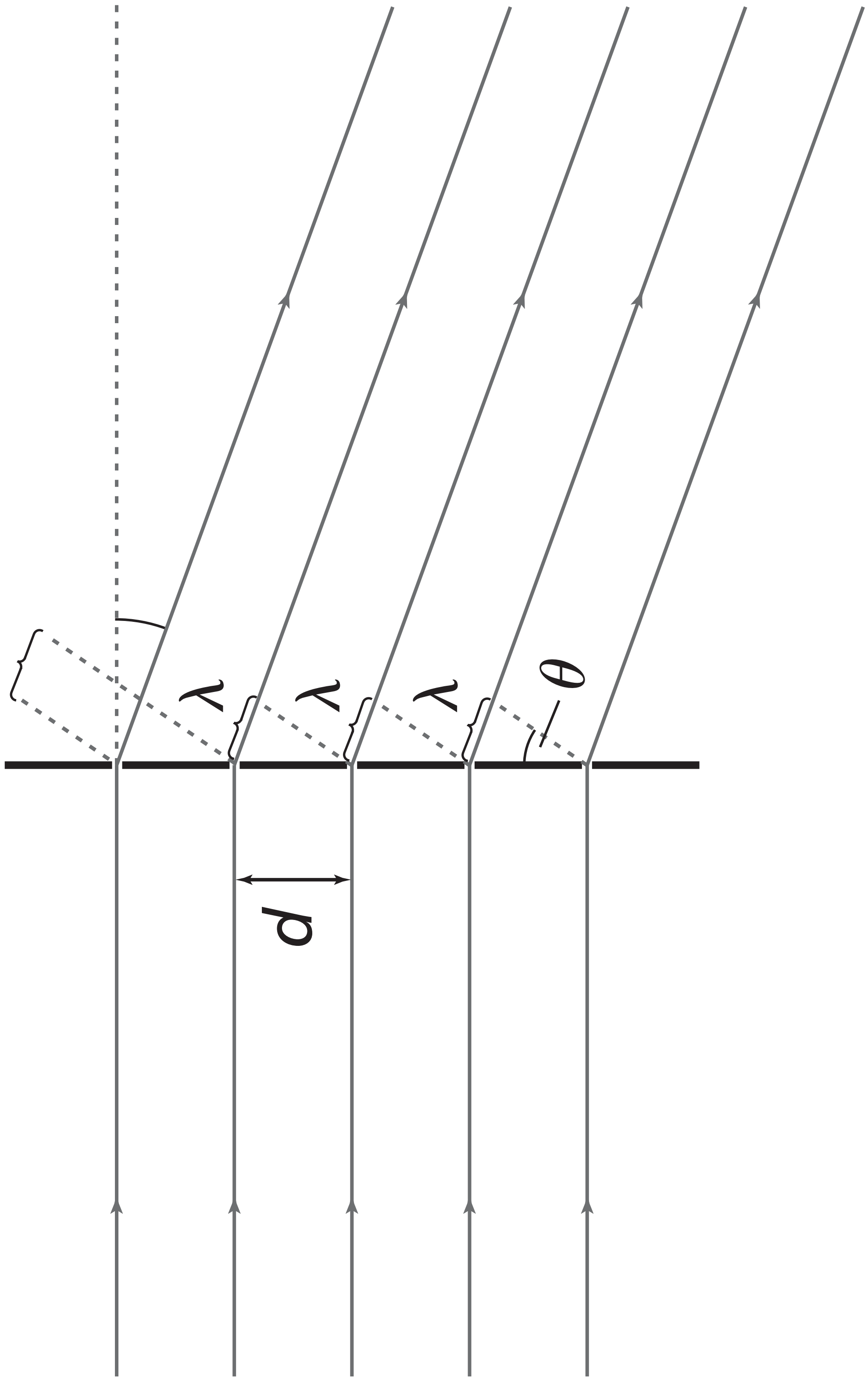
3. Consider the diagram of the light rays from the flashlight. Is the light reflected from a thin film coherent, or incoherent? Explain.

4. Describe the pattern shown in the photograph at the bottom and explain what causes it.

Transparency 19-4

Diffraction Gratings and Light

$$\lambda = d \sin \theta$$



19 Transparency 19-4 Worksheet

Diffraction Gratings and Light

1. A diffraction grating contains many small slits. Does light passing through a diffraction grating behave more like light passing through a double slit or a single slit? How do you know?

2. Is the grating shown in the diagram a transmission grating or a reflection grating? Justify your answer.

3. What wave property can be measured by using a diffraction grating?

4. If there are 5000 lines per cm in a diffraction grating, what is the value of d in meters for the grating?

5. For the diffraction grating in problem 4, what is the wavelength in meters of the light if θ is 17°?

6. Wavelength of light is usually expressed in units of nanometers, which is 10^{-9} m. What is the wavelength in problem 5 in units of nanometers?

Date ____________ Period ____________ Name ____________________

CHAPTER 19

Chapter Assessment

Understanding Physics Concepts

For each description on the left, write the letter of the matching term on the right.

_____ **1.** a diffraction grating formed using a reflective surface

_____ **2.** a diffraction grating made on transparent glass

_____ **3.** a diffraction grating made using lasers and mirrors

_____ **4.** interference that produces a bright band in the pattern on a screen

_____ **5.** light from two or more wave sources that superimpose to produce smooth wave fronts

_____ **6.** light of only one wavelength

_____ **7.** light that has unsynchronized wave fronts and produces no regular patterns

_____ **8.** interference that produces a dark band in the pattern on a screen

a. coherent
b. constructive
c. destructive
d. holographic
e. incoherent
f. monochromatic
g. reflection
h. transmission

For each description on the left, write the letter of the matching term on the right.

_____ **9.** the diameter of the circular aperture of a lens

_____ **10.** the distance between the lens and an object

_____ **11.** a constant of proportionality

_____ **12.** the distance between the lens and the image it produces

_____ **13.** the distance between objects at the limit of resolution

_____ **14.** the distance between the centers of the bright spots of two images produced by a lens

_____ **15.** the wavelength of the light used

a. 1.22
b. λ
c. L_{obj}
d. L
e. x_1
f. x_{obj}
g. D

Circle the letter of the choice that best completes the statement or answers the question.

16. Sunlight is an example of ______.

a. a laser
b. coherent light
c. incoherent light
d. monochromatic light

17. Young's experiments on wave properties investigated ______.

a. diffraction gratings
b. double-slit interference
c. single-slit diffraction
d. wavelets

18. The destructive and constructive interference of light that passes through two closely spaced slits produces ______.

a. a continuous white band
b. a single band of one color
c. a single continuous spectrum
d. interference fringes

19. The paths of light waves that come from two slits and that interfere to form first-order bands ______.

a. are exactly the same length
b. are parallel
c. are perpendicular
d. differ in length by one wavelength of the light

20. When light passes through a single slit, which of the following appears?

a. a bright central band, with dimmer, narrower bands to the side
b. a dark central band, with bright bands to the sides
c. a series of equally bright bands
d. a single wide bright band

21. To observe single-slit diffraction, the slit width must be ______ the wavelength of the light used.

a. equal to
b. smaller than
c. larger than
d. parallel to

22. Thin-film interference is caused by ______.

a. absorption of colors in a pigment
b. incoherent light changing into reflected coherent light
c. light reflecting off the top of the film only
d. light passing through a thin film

23. The strongest colors reflected in a thin film have wavelengths in the film equal to ______ of the thinnest possible film.

a. the thickness
b. twice the thickness
c. four times the thickness
d. two or four times the thickness, depending upon the number of wave inversion

24. In single-slit diffraction, the ______ is analyzed when determining wavelength from the experiment.

a. bright bands
b. angles between dark bands
c. angles between bright bands
d. width of the central bright band

25. Which of the following slit widths would make the wave nature of light noticeable for a light of wavelength 498 nm?

a. 400 nm
b. 498 nm
c. 4980 nm
d. 498 mm

26. The pattern formed from a diffraction grating is similar to that formed by ______.

a. double-slit interference
b. several overlapping single-slit diffraction patterns
c. single-slit diffraction
d. thin-film interference

27. The brightest spectra produced by diffraction gratings are produced by ______.

a. a grating spectroscope
b. holographic gratings
c. reflection gratings
d. transmission gratings

28. Which number of slits in a diffraction grating produces the narrowest lines?

a. 600 slits/cm
b. 600 slits/mm
c. 4000 slits/cm
d. 4000 slits/m

29. Two closely spaced stars are seen as a single star when a telescope lens has limited ______.

a. diffraction gratings
b. index of refraction
c. reflective ability
d. resolving power

30. According to the Rayleigh criterion, the resolving power of a telescope viewing objects at a fixed distance is a function of the wavelength of the light and the ______.

a. distance between the objects
b. diameter of the lens
c. distance between bright centers of the two images
d. length of the telescope

31. The Rayleigh criterion cannot be used to calculate the resolving power of ______.

a. flat glass
b. telescopes
c. microscopes
d. the human eye

32. The effects of diffraction on the ability of telescopes to distinguish between closely spaced stars can be reduced by ______.

a. increasing the size of the mirror
b. decreasing the size of the mirror
c. using colored filters
d. reducing the amount of light entering the telescope

Thinking Critically

Answer the following questions. Use complete sentences.

1. How can you look at a pattern on a screen and determine whether it was produced by double-slit interference, single-slit diffraction, or a diffraction grating?

2. In a double-slit experiment, a piece of glass is placed in front of one of the slits. The glass shifts the light wave so it is not in phase with the other slit, but it does not change its wavelength. Describe and explain the pattern seen on the screen.

3. Monochromatic yellow light is used in a double-slit experiment, and a pattern is observed on the screen. How would the pattern change if a monochromatic green light were used instead of the yellow light? Explain your answer.

4. Why wouldn't a double-slit experiment be as effective to measure the wavelength of sound?

Applying Physics Knowledge

Answer the following questions. Show your calculations.

1. Two slits are separated by 1.72×10^{-5} m, and the screen is 0.650 m away from the slits. Monochromatic violet light with a wavelength of 450 nm passes through the slits. How far from the central band does the first band of violet light appear?

2. Two slits are 1.95×10^{-5} m apart. A red laser beam falls on the slits. A first-order bright band appears 4.42×10^{-2} m from the central bright band. The screen is 1.25 m from the slits. What is the wavelength of the light?

3. A monochromatic light with a wavelength of 570 nm passes through two slits that are 1.90×10^{-5} m apart and are 0.800 m from the screen. In millimeters, what is the distance between the first-order bright band and the central bright band?

4. The same monochromatic light with a wavelength of 570 nm passes through a single slit with a width of 0.0900 mm. The distance from the slit to the screen remains at 0.800 m. In millimeters, what is the width of the central bright band?

5. A thin film of oil rests on top of a pool of water with a thickness of 90 nm. When white light incident on the film is reflected, what colors are seen? The refractive index of the oil is $n_{oil} = 1.45$.

6. A certain diffraction grating has 6.00×10^{3} lines per centimeter. The screen is 0.400 m from the grating. Monochromatic light shines on the grating, and the first-order line in the pattern is 12.9 cm from the central line. What is the wavelength of the light in nanometers?

7. At what angle is the first-order line for violet light with a wavelength of 400 nm produced by a diffraction grating that has 1.00×10^{4} lines per centimeter?

8. Two stars that are 1.50×10^{8} km apart are viewed through a telescope at a distance of 10.5 light years. What is the smallest diameter of telescope that could resolve these two objects? Use a wavelength of $\lambda = 550$ nm in your calculations.

CHAPTER 20

Reproducible Pages Contents

Static Electricity

CHAPTER 20

Mini Lab Worksheet

Investigating Induction and Conduction

Use a balloon and an electroscope to investigate charging by induction and charging by conduction.

1. **Predict** what will happen if you charge a balloon by rubbing it with wool and bring it near a neutral electroscope.
2. **Predict** what will happen if you touch the balloon to the electroscope.
3. **Test** your predictions.

Analyze and Conclude

4. **Describe** your results.

5. **Explain** the movements of the leaves in each step of the experiment. Include diagrams.

6. **Describe** the results if the wool had been used to charge the electroscope.

Date ______ Period ______ Name ______

CHAPTER 20

Physics Lab Worksheet

Materials

- 15-cm plastic ruler
- thread
- ring stand with ring
- masking tape
- materials to be charged, such as rubber rods, plastic rods, glass rods, PVC pipe, copper pipe, steel pipe, pencils, pens, wool, silk, plastic wrap, plastic baggies, waxed paper, and aluminum foil

Charged Objects

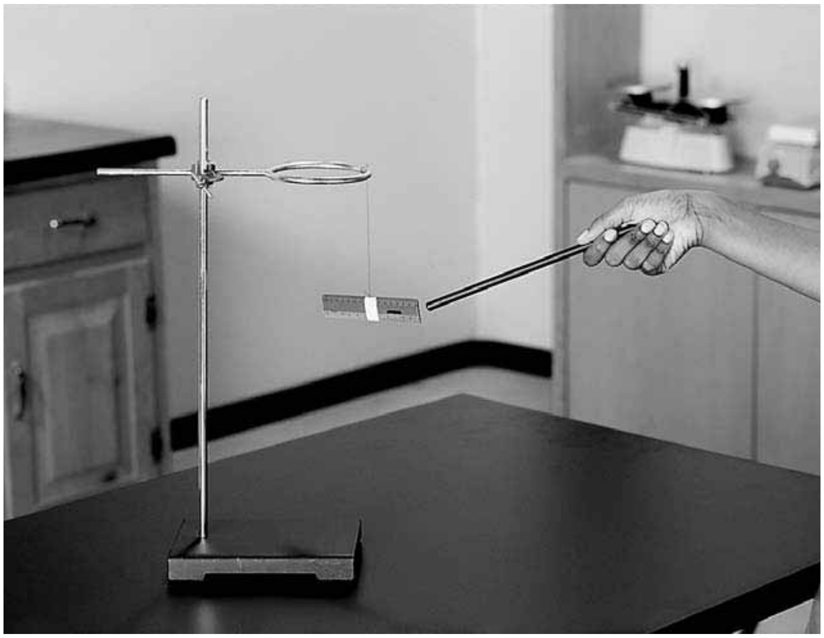
In this chapter, you observed and studied phenomena that result from the separation of electric charges. You learned that hard rubber and plastic tend to become negatively charged when they are rubbed, while glass and wool tend to become positively charged. But what happens if two objects that tend to become negatively charged are rubbed together? Will electrons be transferred? If so, which material will gain electrons, and which will lose them? In this physics lab, you will design a procedure to further your investigations of positive and negative charges.

Question

How can you test materials for their ability to hold positive and negative charges?

Objectives

- **Observe** that different materials tend to become positively or negatively charged.
- **Compare and contrast** the ability of materials to acquire and hold positive and negative charges.
- **Interpret data** to order a list of materials from strongest tendency to be negatively charged to strongest tendency to be positively charged.



Data Table					
Material 1	**Material 2**	**Charge on Ruler (+, −, 0)**	**Observation of Ruler's Movements**	**Charge on Material 1 (+, −, 0)**	**Charge on Material 2 (+, −, 0)**

Procedure

1. Use the lab photo as a guide to suspend a 15-cm plastic ruler. It is advisable to wash the ruler in soapy water, then rinse and dry it thoroughly before each use, especially if it is a humid day. The thread should be attached at the midpoint of the ruler with two or three wraps of masking tape between the thread and ruler.
2. Use the following situations as a reference for types of charges a material can have: 1) a plastic ruler rubbed with wool gives the plastic ruler an excess negative charge and the wool an excess positive charge, and 2) a plastic ruler rubbed with plastic wrap gives the plastic ruler an excess positive charge and the plastic wrap an excess negative charge.
3. Design a procedure to test which objects tend to become negatively charged and which tend to become positively charged. Try various combinations of materials and record your observations in the data table.
4. Develop a test to see if an object is neutral. Remember that a charged ruler may be attracted to a neutral object if it induces a separation of charge in the neutral object.
5. Be sure to check with your teacher and have your procedure approved before you proceed with your lab.

Analyze

1. **Observe and Infer** As you brought charged materials together, could you detect a force between the charged materials? Describe this force.

2. **Formulate Models** Make a drawing of the charge distribution on the two materials for one of your trials. Use this drawing to explain why the materials acted the way they did during your experiments with them.

3. **Draw Conclusions** Which materials hold an excess charge? Which materials do not hold a charge very well?

4. **Draw Conclusions** Which materials tend to become negatively charged? Which tend to become positively charged?

5. **Interpret Data** Use your data table to list the relative tendencies of materials to be positively or negatively charged.

Conclude and Apply

1. Explain what is meant by the phrases *excess charge* and *charge imbalance* when referring to static electricity.

2. Does excess charge remain on a material or does it dissipate over time?

3. Could you complete this physics lab using a metal rod in place of the suspended plastic ruler? Explain.

4. Clear plastic wrap seals containers of food. Why does plastic wrap cling to itself after it is pulled from its container?

Going Further

Review the information in your textbook about electroscopes. Redesign the lab using an electroscope, rather than a suspended ruler, to test for the type of charge on an object.

Real-World Physics

Trucks often have a rubber strap or a chain that drags along the road. Why are they used?

Physics Online

To find out more about static charge, visit the Web site: **physicspp.com**

Date ____________ Period ____________ Name ____________________

CHAPTER 20

Study Guide

Static Electricity

Vocabulary Review

Write the term that correctly completes the statement. Use each term once.

charging by conduction	**Coulomb's law**	**grounding**
charging by induction	**electroscope**	**insulators**
conductor	**electrostatics**	**neutral**
coulomb	**elementary charge**	

1. ____________________ An atom is said to be _____ if the positive charge of the nucleus exactly balances the negative charge of the surrounding electrons.

2. ____________________ _____ states that the magnitude of the force between charge q_A and charge q_B, separated by a distance r, is proportional to the magnitude of the charges and inversely proportional to the square of the distance.

3. ____________________ _____ is the process of connecting a body to Earth to eliminate excess charge.

4. ____________________ The study of electric charges that can be collected and held in one place is called _____.

5. ____________________ The _____ is the SI standard unit of charge.

6. ____________________ Giving a neutral object a charge by touching it with a charged object is called _____.

7. ____________________ An electric _____ is a material through which charges move about easily.

8. ____________________ A device that helps determine charge using pieces of metal foil is a(n) _____.

9. ____________________ Materials through which electrical charges do not move easily are electrical _____.

10. ____________________ Separating the charges in an object without touching it is called _____.

11. ____________________ The magnitude of the charge of an electron is the _____.

Section 20.1 Electric Charge

In your textbook, read about charged objects and a microscopic view of charge on pages 542–544.

For each statement below, write* true *or rewrite the italicized part to make the statement true.

1. ____________________ You can determine whether an object is positively or negatively charged by bringing an object with *the opposite* charge near it.

2. ____________________ Pulling two side-by-side pieces of tape off the surface of a table gives the pieces of tape *the same* charge.

3. ____________________ Objects that have the same charge *attract* one another.

4. ____________________ In a neutral atom, the number of *neutrons* must equal the number of electrons.

5. ____________________ The designation of positive and negative for charges was first used by *J.J. Thomson*.

6. ____________________ Touching a charged object often causes it to *lose* its charge.

7. ____________________ The force produced by charged objects can be *greater* than gravitational force.

8. ____________________ Removing electrons from an atom requires *friction*.

9. ____________________ A thundercloud becomes charged when positive and negative charges are *separated*.

10. ____________________ Atoms become charged when *protons* are removed or added.

Write + for positive or − for negative to indicate the charge that each material tends to collect when it is rubbed.

______ **11.** plastic

______ **12.** wool

______ **13.** hard rubber

______ **14.** glass

Answer the following questions. Use complete sentences.

15. What are the negative and positive parts of an atom? Where are they located?

____

____

____

16. How is charge acquired when two neutral objects are rubbed together? Which object becomes negatively charged and which becomes positively charged?

____

____

____

In your textbook, read about conductors and insulators on pages 544–545.

Place an X in the appropriate column to indicate whether each example is an insulator or a conductor.

Example	Insulator	Conductor
17. a material through which a charge does not move easily		
18. glass		
19. air changed to a plasma		
20. aluminum		
21. an object that, when held at the midpoint and rubbed only on one end, becomes charged only at the rubbed end		
22. copper		
23. dry wood		
24. a material through which charges move about easily		
25. most plastics		
26. carbon in the form of graphite		
27. carbon in the form of diamond		
28. an object that has very few electrons that are about to move about freely		
29. dry air		
30. an object in which charges applied to one area spread quickly over the entire object		
31. a cotton sheet		
32. a rubber tire		
33. a wool blanket		
34. a dime		
35. a silver ring		

Section 20.2 Electric Force

In your textbook, read about forces on charged bodies on pages 546–548.

Answer the following questions. Use complete sentences.

1. How does a charged rod brought near a suspended charged rod cause the suspended rod to move if the rods are not touching?

____

____

____

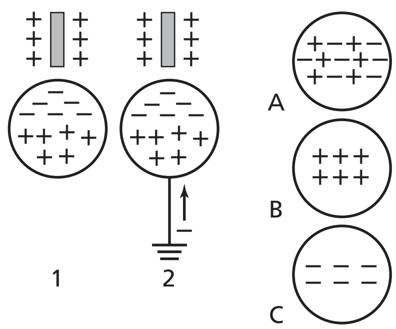
2. Why are metal leaves, rather than paper or plastic leaves, used to indicate charge in an electroscope?

____

____

____

3. A rod with a positive charge is placed near an uncharged metal sphere.



a. What is happening in Figure 1? What is the process called?

____

____

____

____

b. If the bottom of the sphere is grounded, as in Figure 2, electrons are attracted to the positive charge. What does this do to the overall charge on the sphere?

____

____

c. If the connection to the ground is broken and the charged rod is then removed, will the sphere look like Figure A, B, or C? Why?

____

____

d. If the charged rod is first removed and the ground is then broken, will the sphere look like Figure A, B, or C? Why?

____

____

e. What would happen if the rod were negatively charged and the ground was broken before the charged rod was removed?

____

____

In your textbook, read about Coulomb's law on pages 549–552.

Circle the letter of the choice that best completes the statement or answers the question.

According to Coulomb's law, the magnitude of the force on a charge q_A caused by charge q_B a distance r away can be written as $F = \frac{Kq_Aq_B}{r^2}$.

4. The force, F, ______ with the square of the distance between the centers of two charged objects.

a. varies directly

b. varies inversely

c. varies negatively

d. doesn't vary

5. The force, F, ______ with the charge of the two charged objects.

a. varies directly

b. varies inversely

c. varies negatively

d. doesn't vary

6. When the charges are measured in coulombs, the distance is measured in meters, and the force is measured in newtons, the constant, K, is ______ $N \cdot m^2/C^2$.

a. 1.60×10^{-19}

b. 6.67×10^{-11}

c. 9.0×10^{9}

d. 6.24×10^{18}

7. Coulomb's law can be used to determine ______ of an electrical force.

a. the direction

b. the magnitude

c. the charge

d. both the direction and magnitude

8. One coulomb is the amount of charge in ______ electron(s).

a. 1.60×10^{-19}

b. 1

c. 9.0×10^{9}

d. 6.24×10^{18}

9. In an arrangement of three or more point charges, the direction of the resultant force on any charge can be determined by ______.

a. using the Coulomb's law formula

b. finding the vector sum of the forces acting on that charge

c. measuring and adding up the charges on each point charge

d. adding or subtracting the size and sign of each of the charges

Answer the following questions. Show your calculations.

10. At what distance would the repulsive force between two electrons have a magnitude of 2.00 N?

11. At what distance would the repulsive force between two protons have a magnitude of 2.00 N?

12. In Question 10, what would the repulsive force be if the distance between the electrons were doubled?

In your text, read about application of electrostatic forces on pages 552–553.
Answer the following questions. Use complete sentences.

13. Give two examples of applications of electric forces.

____

____

____

14. On dry days with little moisture in the air, you can often get a small electric shock of static electricity when you touch a metal object. Why does relatively low humidity produce this effect?

____

____

____

____

Date ______________ Period ______________ Name ______________________

CHAPTER 20

Section 20-1 Quiz

1. Compare and contrast gravitational and electrostatic forces.

2. The driver of a car slides across the seat when exiting the car. Upon touching the door, the driver feels a shock. What happened?

3. You suspend a neutral metal rod from an insulating thread and then touch the rod with a negatively charged plastic ruler. What happens?

4. You rub one end of a glass rod with silk, and then you bring a negatively charged plastic ruler near the glass rod. What happens?

5. Describe the particles that make up a neutral atom. What could you do to give the atom a positive charge?

CHAPTER 20

Section 20-2 Quiz

1. The proton that makes up the nucleus of the hydrogen atom attracts the electron that orbits it. Does the electron attract the proton with less force, more force, or the same amount of force?

____

____

____

2. A proton at a particular distance from a charged particle is repelled with a given force.

a. What is the sign of the particle?

____

b. How much will the force decrease when the proton is three times as far from the particle?

____

c. Five times as far?

____

3. How did Coulomb make sure that the pair of spheres he was using had equal charges?

____

____

____

4. Two table tennis balls hang with their centers 10.0 cm apart. The charge on ball A is $+12\times10^{-9}$ C, and the charge on Ball B is -15×10^{-9} C. What is the force of attraction between the balls?

5. Two identical, small spheres are charged, touched together, and then separated. Their centers are 12 cm apart. They repel one another with a force of 3.0×10^{-5} N. How much charge do they have?

CHAPTER 20

Reinforcement

Materials

- plastic wrap
- cotton cloth
- aluminum foil
- paper punch

Jumping Disks

Problem

Can static charges move things?

Procedure

1. Tear off a sheet of plastic wrap about 30 cm by 30 cm.
2. Lay the plastic wrap on a clean surface and use the cotton cloth to make it smooth and flat.
3. Use the paper punch to cut small round disks from aluminum foil.
4. Place a small pile of aluminum foil disks in the center of the plastic wrap.
5. Slowly lift the plastic wrap by one end.
6. Observe and record the behavior of the aluminum disks.

Results

1. What did the aluminum pieces do first? Why?

____

____

____

2. Was the electric force holding the aluminum to the plastic stronger or weaker than the force of gravity? How do you know?

____

____

____

3. What happened to the aluminum after a few seconds? Why?

____

____

____

____

Date ________________ Period ________________ Name ______________________________

CHAPTER 20

Enrichment

Materials

- clear plastic tube with end caps
- plastic foam peas or tiny pieces of polystyrene
- wool cloth

Static Electricity

Static Tubes

Procedure

1. Cover one end of the plastic tube with an end cap, but leave the other end open.
2. Carefully transfer a small handful of polystyrene pieces into the tube, and then cover the open end.
3. Remove any polystyrene that is clinging to the outside of the tube. Rub the tube with a wool cloth.
4. Turn the tube on one end to try to move the polystyrene from one end of the tube to the other.
5. Bring your fingers near the tube and place them on the tube. Notice how the polystyrene inside is affected.

Results

1. What happened when you first put the polystyrene in the tube? Why does this happen?

____

____

____

____

____

____

2. What happened when you rubbed the tube with the wool cloth?

____

____

____

____

____

____

20 Enrichment

3. What happened when you tried to move the polystyrene pieces from one end of the tube to the other? Why did this happen?

Consider what happened to the polystyrene pieces in the tube. Then answer the following questions.

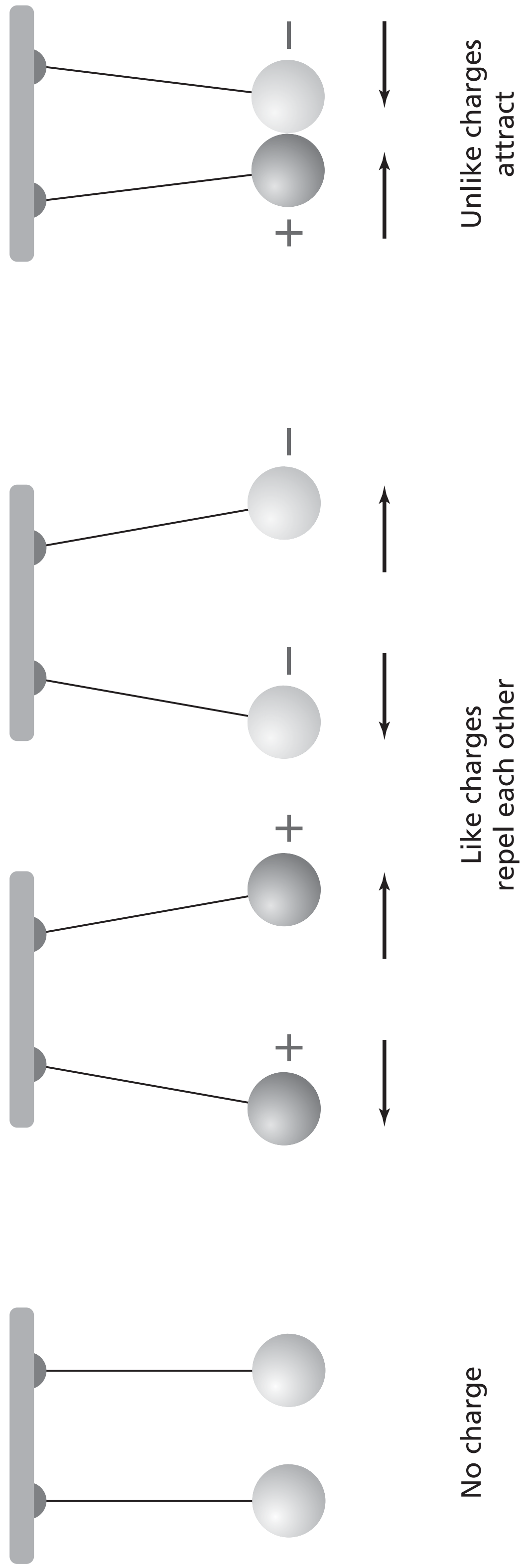
4. What happened when you moved your fingers along the outside of the tube? Why did this happen?

5. Predict how the results would be different if you used a metal tube instead of a plastic tube.

6. Based on your findings here, if you were to design safety domes to shelter campers during lightning storms, would you construct the domes of plastic or metal? Explain.

Transparency 20-1

Rule of Electric Charges



Date ____________ Period ____________ Name ______________________

20 Transparency 20-1 Worksheet

Rule of Electric Charges

1. How many types of electric charges are there?

____

2. What general rule describes the way in which electric charges interact with each other?

____

____

3. If you placed a negatively charged object between the two pith balls in the second diagram, what would happen? Why?

____

____

____

4. If you placed a negatively charged object between the two pith balls in the third diagram, what would happen? Why?

____

____

5. If you charged only one of the pith balls in the first diagram, what would happen?

____

6. Where do charges come from? How can pith balls with no charge become charged?

____

____

____

7. If a piece of wool is rubbed against two identical rubber rods suspended by thread, and all three objects become charged, how will they react when brought near each other? Why?

____

____

____

8. What will happen to the pith balls in the last three diagrams over time? Why?

____

____

____

Transparency 20-2

Determination of Charge

Date ______________ Period ______________ Name ______________________

20 Transparency 20-2 Worksheet

Determination of Charge

1. In order for an electroscope to work, what must be true about the knob, the leaves, and the rod connecting the two?

____

2. Why are thin metal leaves used in an electroscope?

____

____

____

3. If you were to touch a negatively charged object to the knob of the electroscope in the diagram on the left, what would happen? Why?

____

____

____

4. The diagram in the middle shows a negatively charged object touched to the electroscope in the diagram on the left. What happened?

____

____

____

5. The diagram on the right shows a positively charged object touched to the electroscope in the diagram on the left. What happened?

____

____

____

6. What conclusion would you reach if you touched the knob of the electroscope in the diagram on the left with a rod and the leaves did not move? Why?

____

____

7. How could you use a positively charged electroscope to determine the charge on a rod?

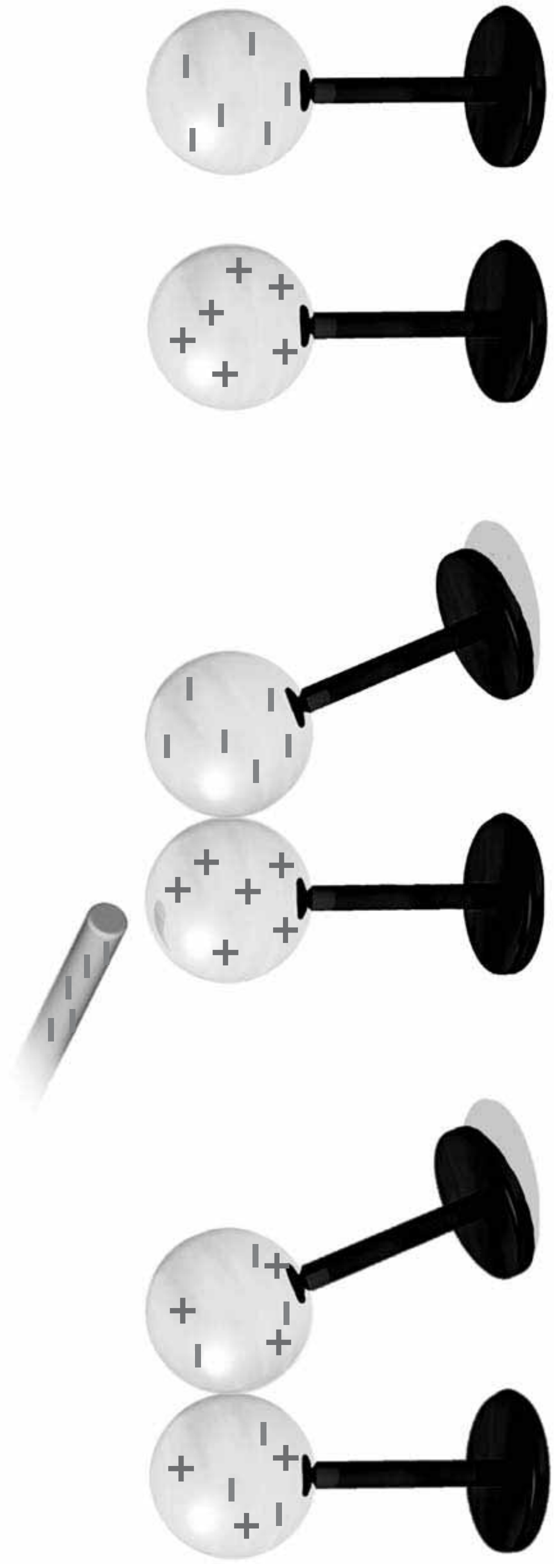
____

____

____

Transparency 20-3

Charging by Induction



Date ______________ Period ______________ Name ______________________________

20 Transparency 20-3 Worksheet

Charging by Induction

1. What must be true about the stands on which the spheres rest in order to demonstrate charging by induction?

2. What happens when the negatively charged rod is brought close to the sphere?

3. What would happen if the charge rod were removed, but the spheres were left in contact?

4. How can you keep the spheres charged as they are in the pair of spheres on the right?

5. What happens to the charge on the rod during this process?

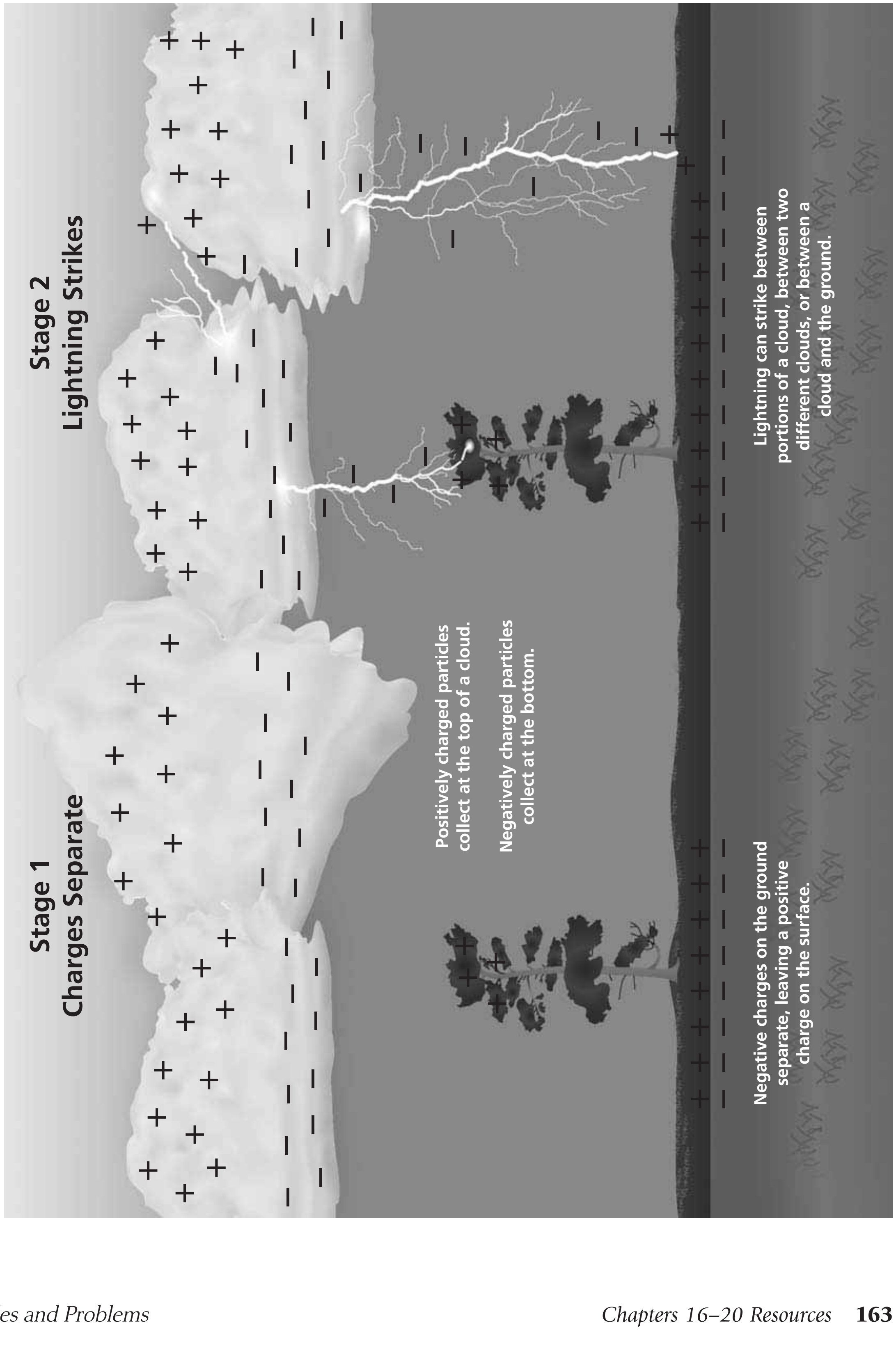
6. How could you use the rod and one sphere to create a positively charged single sphere?

7. Could you create two charged spheres with a positively charged rod rather than a negatively charged one? Why or why not?

CHAPTER 20

Transparency 20-4

Cloud-to-Ground and Cloud-to-Cloud Lightning



20 Transparency 20-4 Worksheet

Cloud-to-Ground and Cloud-to-Cloud Lightning

1. What is the charge on the tree and ground before the cloud appears overhead?

2. How do charges tend to arrange themselves when they separate in clouds?

3. What causes the separation of charge in the tree and ground when the cloud moves overhead?

4. How might a discharge occur within a single cloud? What would that do to the overall charge of the cloud?

5. How might a discharge occur between two clouds? What would that do to the overall charge of the two clouds?

6. Would it be likely that lightning would strike the same tree twice in a brief period of time? Why or why not?

7. Lightning often strikes the highest object in the area. Lightning rods often are placed on top of tall buildings. What is their purpose?

8. In what ways are lightning discharges similar to and different from the kind of shock you get when touching something metal after walking across a rug?

Date ____________ Period ____________ Name ______________________

CHAPTER 20

Chapter Assessment

Static Electricity

Understanding Physics Concepts

Circle the letter of the choice that best completes the statement or answers the question.

1. Two electric charges with the same sign _____.

a. attract each other
c. have no effect on each other
b. repel each other
d. annihilate each other

2. For two particles such as protons with both electric and gravitational forces, the _____.

a. electric forces will be stronger
b. gravitational forces will be stronger
c. electric and gravitational forces will be the same
d. strength of the forces depends on the object

3. All electric charges are multiples of the charge on a(n) _____.

a. coulomb
c. electron
b. neutron
d. atom

4. The charge on a rubber rod that has been rubbed with wool is _____.

a. positive
c. neutral
b. negative
d. unchanged by the wool

5. The electric force between two charges is _____ to the square of the distance between them.

a. not related
c. directly proportional
b. equal
d. inversely proportional

6. While many properties are similar, one important difference between electric and gravitational forces is that unlike gravity, electric charge _____.

a. can be transferred
c. obeys an inverse-square law
b. operates at a distance
d. remains constant over time

7. When wool and plastic are rubbed together, the plastic becomes _____.

a. positively charged because it loses electrons to the wool
b. negatively charged because it loses electrons to the wool
c. positively charged because it gains electrons from the wool
d. negatively charged because it gains electrons from the wool

8. Transferring charge by touching one object to another is called _____.

a. charging by induction
c. charging by friction
b. charging by conduction
d. charging by transfer

9. The SI unit of electric charge is the ______.

a. volt **c.** coulomb

b. watt **d.** ampere

10. Air can become a conductor when it becomes ______.

a. dry **c.** discharged

b. a plasma **d.** wet

11. An important difference between gravitational and electric force is that gravitational force is always ______.

a. attractive **c.** stronger

b. repulsive **d.** downward

12. Charging by induction ______.

a. creates charge by transferring charges from one object to another

b. results in a permanent charge

c. creates charges within an object

d. separates charges within an object

13. When an electroscope is charged, its leaves separate because ______.

a. unlike charges repel

b. similar charges exert force on each other over a distance

c. positive charges spread over the metal leaves

d. magnetic forces spread the metal leaves apart

14. If a negatively charged rod is brought near a negatively charged electroscope, ______.

a. there will be no effect

b. the leaves will fall

c. the leaves will spread farther apart

d. the electroscope will become positively charged

15. The force that charge q_A exerts on charge q_B is ______ the force that charge q_B exerts on charge q_A.

a. opposite and equal to

b. opposite and greater than

c. opposite and less than

d. the same as

Thinking Critically

Answer the following questions. Use complete sentences or show your calculations.

1. The electric force between two charged spheres is 64 N. What will the magnitude of the force be if the size of each charge is doubled and the distance between the spheres is doubled?

2. How can you determine whether the charge on an object is positive or negative?

____

____

____

3. Bits of paper are attracted to a charged comb or rod even though they have no net charge. How is this possible?

____

____

____

4. A positive charge of 1.8×10^{-6} C and a negative charge of -1.0×10^{-6} C are 0.014 m apart. What is the attractive force between the two particles?

5. Draw a diagram and explain what causes a cloud-to-ground lightning strike.

6. Some lightning bolts travel from cloud to cloud rather than from cloud to ground. How might this occur?

____

____

____

7. A comb drawn through a person's hair on a dry day causes 1.0×10^{12} electrons to stick to the comb.

a. Is the force between the comb and the hair attractive or repulsive?

____

b. What is the magnitude of the force when the comb is 10.0 cm from the person's hair?

8. Automobile tires are made of rubber infused with carbon and metal wires. Durability aside, why not make tires out of pure rubber?

____

____

____

____

9. The leaves on an electroscope are separated. A charged rod is touched to the ball of the electroscope and the leaves move even farther apart.

a. What do you know about the charge on the rod?

____

____

____

b. A piece of wool that has been rubbed on a plastic ruler is touched to the electroscope. The leaves collapse. Was the electroscope positively or negative charged? How do you know?

____

____

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10. Some people heat rooms with a wood stove. You often see a kettle or open pan filled with water sitting on top of the stove. In terms of static electricity, what is the purpose of this?

____

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Applying Physics Knowledge

Answer the following questions. Use complete sentences or show your calculations.

1. When a television is on, the picture is produced when electrons are fired at the back of the screen.

a. Why does a television screen collect more dust than other objects in the room, even though it is a vertical surface?

b. As you are watching a show on television, you notice how dusty the screen is. Is it a good idea to wipe the dust from the screen while the television is on? Why or why not?

2. A negative charge of -6.0×10^{-6} C exerts an attractive force of 65 N on a second charge 0.050 m away. What is the magnitude of the second charge?

3. A proton has a mass of 1.67×10^{-27} kg and a charge of 1.60×10^{-19} C.

a. What is the weight (gravitational force) on a single proton at Earth's surface?

b. How far apart must two protons be if the electric force between them is equal to the weight of a single proton?

4. A positive charge, B, of 4.5×10^{-7} C has two other charges nearby, all located along the same straight line. Charge A is 2.2×10^{-6} C and is located 2.0 cm to the left of B. Charge C is 9.0×10^{-5} C and is 12 cm to the right of B.

a. What is the magnitude of the two forces acting on B?

b. What is the magnitude of the net force acting on Charge B?

Answer Key

Chapter 16

Mini Lab

Analyze and Conclude

5. When the lightbulb is dim, reds and oranges are visible.
6. When the lightbulb is bright, blues and violets appear.
7. The dim lightbulb is cooler to the touch than the bright lightbulb, so the filament giving off the light must be hotter when brighter. The cool temperature corresponds to long-wavelength light and the hot temperature corresponds to short-wavelength light.

Physics Lab

Sample Data

Light Source	Observations
1 incandescent light	not polarized
2 fluorescent light	slightly polarized
3 mirrored surface	polarized
4 white paper	not polarized
5 black paper	polarized
6 liquid crystal display	polarized
7 two polarizing filters	nothing is visible at the cross-polarized point
8 plastic between filters	plastic is visible at the cross-polarized point

Analyze

1. Incandescent light is not polarized. It produces light in many planes.
2. Fluorescent light is slightly polarized. As the polarized filter is rotated, the light does dim somewhat.
3. Shiny surfaces produce polarized light.
4. Reflected light from a white paper is mostly unpolarized. Light waves are produced in all planes.
   Reflected light from a black source is mostly polarized because black absorbs much of the unpolarized light.
5. Liquid crystal displays produce polarized light. When the filter is rotated, at a certain point, the display becomes all black.

Conclude and Apply

1. No light will pass through the polarizing filters when they are cross-polarized.
2. The plastic protractor rotates the plane of polarized light after it exits the first polarizing filter, so some amount of intensity of the light can pass through the second polarizing filter, as explained by Malus's law.
3. The majority of light is polarized when reflecting off shiny surfaces or when passing through optically active media such as liquid crystal displays.

Going Further

1. Blue sky is highly polarized because the blue color comes from a single scattering effect.
2. Cloud-reflected light is not polarized because there is scattering of light in many planes.

Real-World Physics

1. Polarized lenses help block glare off of reflected surfaces.
2. Cars have many types of shiny surfaces that can easily produce polarized light.

Chapter 16 Study Guide

Vocabulary Review

1. illuminance
2. complementary color
3. luminous intensity
4. luminous flux
5. polarized
6. secondary color
7. luminous source
8. ray model of light

9. transparent
10. illuminated source
11. primary color
12. primary pigment
13. secondary pigment
14. translucent
15. opaque
16. Malus's law
17. observed light frequency
18. Doppler shift

Section 16-1 Illumination

1. true
2. luminous
3. true
4. a transparent
5. c
6. a
7. b
8. c
9. a
10. c
11. a
12. lux
13. lx
14. lumen
15. lm
16. candela
17. cd
18. emits
19. reflects
20. incandescent
21. candela
22. rate
23. illumination
24. one-quarter
25. $E = \dfrac{P}{4\pi r^2}$
26. r
27. perpendicular
28. point
29. d
30. c
31. g
32. e
33. f
34. a
35. b
36. h

Section 16-2 The Wave Nature of Light

1. No light is projected there.
2. magenta
3. cyan
4. yellow
5. white
6. primary
7. secondary
8. secondary
9. green
10. red
11. blue
12. one primary color
13. two primary colors
14. subtractive
15. yellow, cyan, and magenta
16. red, green, and blue
17. blue
18. red and green
19. green and blue
20. red
21. black
22. true
23. perpendicular
24. true
25. in the same direction as
26. by 50 percent
27. true
28. dimmer
29. no light can come through
30. true
31. true
32. toward red
33. does hold
34. away from
35. true
36. light
37. true

Section 16-1 Quiz

1. a. $E = \frac{P}{4\pi r^2}$

$= \frac{1750\ \text{lm}}{4\pi(3.0\ \text{m})^2}$

$= 15\ \text{lm/m}^2$

$= 15\ \text{lx}$

b. Illuminance increases; this illustrates an inverse-square relationship because as the distance decreases, the illumination increases. If the distance is reduced by one-half, illuminance increases by a factor of four.

2. They are similar in that they both reflect some light. They are different in that transparent media transmit light but opaque media do not.

3. $d = vt$

$= (3.00\times10^8\ \text{m/s})(8.3\ \text{min})(60\ \text{s/1 min})$

$= 1.5\times10^{11}\ \text{m}$

Section 16-2 Quiz

1. Possible answers include: Diffraction occurs when the wavefront of light is cut by an edge, allowing the circular wavelet generated by the Huygens' points near the edge to propagate as circular waves; or the effect of a polarizing filter is only possible with a wave model for light.

2. No; when white light falls on a red scarf, it appears red. However, when blue light falls on a red scarf, it appears black.

3. A polarizing filter is made of long, thin molecules, which are aligned in the same direction perpendicular to the axis of polarization. Light waves travel in all directions. The lenses of polarizing sunglasses only let through the light waves that are aligned with the axis of polarization.

4. On spectrographs of distant galaxies, the spectral lines of familiar elements appeared at longer wavelengths than expected. The lines were shifted toward the red end of the spectrum. Hubble concluded from this Doppler effect with light that the galaxies were moving away from Earth.

Chapter 16 Reinforcement

Adding Colors

Results

Segment	Color	Complementary Color
1	Green	Magenta
2	Red	Cyan
3	Blue	Yellow
4	Cyan	Red
5	Yellow	Blue
6	Magenta	Green
7	White	None

1. Green, red, and blue are primary. These are the three colors from which all other colors can be produced.

2. Cyan, yellow, and magenta are secondary. Secondary colors are those produced by combining two primary colors.

Chapter 16 Enrichment

Making a Spectrograph

1. Possible answers include: I saw lines of color that were spread out across the spectrograph.

2. Student diagrams may vary in detail, depending upon light source and material. Possible answers include the following:

Source A

Source B

3. White light is a mixture of different light frequencies. A prism bends the components of the white light so that the colors of the different frequencies are visible. Different chemical elements produce light made up of different frequencies, so you observe different colors.

Transparency 16-1 Worksheet

Light Transmission Through Objects

1. It is a medium that transmits light clearly.
2. They pass through unchanged.
3. Sample answers: air, glass, some plastics
4. The pencil looks normal, with no distortion.
5. It is a medium that transmits light, but does not permit objects to be seen clearly.
6. They pass through, but are bent in different directions.
7. Sample answers: frosted lightbulbs, frosted glass
8. The pencil is visible but distorted.
9. It is a medium that does not transmit light, but reflects some light.
10. They are absorbed or reflected.
11. Sample answers: brick, pencil
12. You cannot see the pencil. You only see the medium.

Transparency 16-2 Worksheet

Electromagnetic Spectrum

1. It increases to the right.
2. Green light has a shorter wavelength than orange light.
3. Blue light has a shorter wavelength than yellow light. Because frequency is inversely proportional to wavelength, blue light must have a higher frequency.
4. violet, blue, green, yellow, orange, red.
5. orange, yellow, green, violet
6. $1\text{ nm} = 1\times10^{-9}$

   $f = c/\lambda$

   $f_{\text{red in vacuum}} = (3.00\times10^{8}\text{ m/s})/(7.5\times10^{-7}\text{ m})$
   $= 4.0\times10^{14}\text{ Hz}$

   $\lambda_{\text{red in glass}} = (2.0\times10^{8}\text{ m/s})/(4.0\times10^{14}\text{ Hz})$
   $= 5.0\times10^{-7}\text{ m}$
   $= 5.0\times10^{-2}\text{ nm}$

Transparency 16-3 Worksheet

Mixing Colors

1. The primary colors of light are blue, green, and red.
2. The secondary colors of light are magenta, yellow, and cyan.
3. You get white light.
4. The primary pigment colors are magenta, yellow, and cyan.
5. The secondary pigment colors are blue, green, and red.
6. You get black.
7. Each pigment absorbs some light and reflects only the color seen. When pigments are added they absorb more light and reflect less.
8. They are called secondary colors because each is a combination of two primary colors.

Transparency 16-4 Worksheet

Polarizing Light

1. It vibrates in many planes.
2. A polarizer is a device that produces light that vibrates on a single plane.
3. An analyzer is a device used to transmit only the components of already polarized light that are parallel to it, and to study, or analyze, the polarization of light.
4. Both devices are called polarizing filters.
5. They represent the orientation of the polarizing axis of each filter. Only the waves vibrating parallel to that axis can pass through.
6. Only the light that vibrates in the plane defined by the polarizing axis passes through.
7. They are perpendicular to each other.
8. None of the polarized light that reaches the analyzer passes through because its polarizing axis is perpendicular to that of the original polarizer.
9. They are at an angle of approximately 45° to one another.
10. Some of the light passes through—namely, the component that is parallel to the analyzer's polarizing axis.

Chapter 16 Assessment

Light

Understanding Physics Concepts

1. a
2. d
3. b
4. a
5. d
6. b
7. c
8. d
9. b
10. c
11. straight
12. true
13. spectrum
14. perpendicular
15. lumens
16. lux
17. opaque
18. short wavelength
19. glass prism
20. ray model of light
21. diffraction
22. illuminated source
23. inverse-square
24. speed of light

Thinking Critically

1. The ray model of light and the wave model of light are the two models scientists use to explain light's behavior. The ray model of light, which describes light traveling in straight lines, best explains how light interacts with matter and through different media. The wave model of light helps explain phenomena such as diffraction and polarization.

2. Luminous flux is a measure of the total light emitted from a source. The luminous intensity of a point source is a measure of the amount of light that falls on 1 m^2 of a sphere 1 m in radius. Illuminance is a measure of the amount of light striking a specific surface.

3. The illuminance on a surface and the distance the surface is from the light source are related by an inverse-square relationship. In other words, the farther the surface is from the light source, the dimmer the light is by a factor of the square of the distance.

4. No. If light traveled instantaneously it would take no additional time for light to travel across the orbit Earth makes around the Sun. It is this additional time that enabled Ole Roemer to measure the speed of light.

5. When a dandelion is illuminated by white light, the molecules that make up the flower act as dyes that absorb blue light and reflect red and green light, which together are seen as yellow. The process is subtractive.

6. Dyes are molecules. Pigment particles are larger than molecules. Both dyes and pigments are colored materials that absorb certain wavelengths of light and transmit or reflect others.

7. Place a polarizing filter in the path of the light in question. When the light is polarized, there will be one angle of rotation at which no light passes through the filter. When the polarizing axis of the filter is perpendicular to the plane of polarized light, the light will be prevented from passing through.

8. Refraction relies upon the ray model of light to describe how light is bent as it passes into a different medium. Diffraction relies upon the wave model of light to describe the propagation of light as it is distorted and split by an edge or fine grating.

9. The greater the distance of the object, the less will be its apparent shift in position. In other words, the greater the apparent shift in position, the farther the object is from the observer. The light from the star which shifts the least takes the longest time to reach Earth.

10. No; changes in light due to the Doppler shift affect only the apparent wavelength of light as seen by an observer. The speed of light in a vacuum is always constant.

Applying Physics Knowledge

1. $f = \frac{c}{\lambda}$

$= \frac{3.00\times10^{8}\ \text{m/s}}{7.00\times10^{-7}\ \text{m}}$

$= 4.29\times10^{14}$ Hz

2. $E = \frac{P}{4\pi r^2}$

$= \frac{1600\ \text{lm}}{4\pi(2.0\ \text{m})^2}$

$= 32\ \text{lm/m}^2$

$= 32$ lx

3. $P = 4\pi r^2 E$

$= 4\pi(4.1\ \text{m})^2(22\ \text{lx})$

$= 4.6\times10^{3}$ lm

4. luminous intensity $= \frac{P}{4\pi}$

$= \frac{3.00\times10^{3}\ \text{lm}}{4\pi}$

$= 239$ cd

5. $\lambda = \frac{c}{f}$

$= \frac{3.00\times10^{8}\ \text{m/s}}{5.26\times10^{14}\ \text{Hz}}$

$= 5.70\times10^{-7}$ m

6. $\lambda = \frac{c}{f}$

$= \frac{3.00\times10^{8}\ \text{m/s}}{5.50\times10^{14}\ \text{Hz}}$

$= 5.45\times10^{-7}$ m

middle of the spectrum

7. $r = \sqrt{\frac{P}{4\pi E}}$

$= \sqrt{\frac{1750\ \text{lm}}{4\pi(22\ \text{lx})}}$

$= 2.5$ m

8. $P = \left(\frac{510\ \text{lm}}{1\ \text{watt}}\right)(40\ \text{watts})(0.2)$

$= 4080$ lm

$E = \frac{P}{4\pi r^2}$

$= \frac{4080\ \text{lm}}{4\pi(2.0\ \text{m})^2}$

$= 80\ \text{lm/m}^2$

$= 80$ lx

9. $P = \left(\frac{510\ \text{lm}}{1\ \text{watt}}\right)(40\ \text{watts})(0.03)$

$= 612$ lm

$E = \frac{P}{4\pi r^2}$

$= \frac{612\ \text{lm}}{4\pi(2.0\ \text{m})^2}$

$= 10\ \text{lm/m}^2$

$= 10$ lx

Chapter 17

Mini Lab

Analyze and Conclude

1. The image is 1.0 m behind the mirror.
2. The camera is capturing light that is diverging from the mirror surface as if the light originated from a point behind the mirror.

Physics Lab

Sample Data

Step 1—$f = 40$ cm
Step 10—no image is formed
Step 11—a virtual image is formed in the mirror

Data Table

Trial	d_o (cm)	d_i (cm)	h_o (cm)	h_i (cm)
1	95	65	1	0.7
2	85	76	1	0.9
3	50	185	1	250
4	40	cannot meaure	1	cannot measure
5	30	cannot measure	1	cannot measure

Calculation Table					
Trial	$\frac{1}{d_o}$ (cm^{-1})	$\frac{1}{d_i}$ (cm^{-1})	$\frac{1}{d_o}+\frac{1}{d_i}$ (cm^{-1})	f_{calc} (cm)	% error
1	0.011	0.015	0.026	39	3.5%
2	0.012	0.013	0.025	40	0.0%
3	0.020	0.0054	0.025	39	1.5%
4	0.025				
5	0.033				

Analyze

1. See calculation table above.
2. See calculation table above.
3. See calculation table above.

Conclude and Apply

1. Trials 1 through 3 produced real images. Trial 4 did not produce an image. Trial 5 produced a virtual image.
2. Real images are formed when the object position is greater than the focal length.
3. Virtual images are formed when the object position is less than the focal length.

Going Further

1. The image is larger than the object when the object is placed between the mirror and the center of curvature of the mirror. Many smaller mirrors may produce an image that is too blurry for a good observation when the object position is within the focal length.
2. It is difficult to accurately estimate the mirror focal length. Answers will vary. Students may state that having a mirror that is larger, not dirty, or free of scratches would be helpful. A front-surface mirror would be a better quality to mention. It is also difficult to accurately determine where the clearest or sharpest image is located.

Real-World Physics

The light rays from distant planets or stars will be arriving parallel to the principal axis so a sharp image can be obtained.

Chapter 17 Study Guide

Vocabulary Review

1. principal axis
2. specular reflection
3. image
4. plane mirror
5. object
6. diffuse reflection
7. concave mirror
8. virtual image
9. focal point
10. convex mirror
11. real image
12. spherical aberration
13. focal length
14. magnification

Section 17-1 Reflection from Plane Mirrors

1. perpendicular
2. two dimensional
3. true
4. specular
5. diffuse
6. true
7. angle
8. incident
9. normal
10. reflected
11. normal
12. wave
13. angle
14. many
15. diffuse
16. parallel
17. specular
18. An object is a source of light rays that are reflected by a mirrored surface. An object can be either a luminous source or an illuminated source.
19. A plane mirror produces a virtual image, which is behind the mirror.

20. The light from the object reflects from the mirror into the viewer's eye. The viewer's brain interprets this light as if it had traveled in a straight line from a source behind the mirror.
21. The term *mirror image* refers to the fact that your image in a plane mirror is the same distance from the mirror as you are. Also, it has the same orientation and is the same size as you.
22. Draw a geometric model, and use the law of reflection and similar triangle geometry.
23. No, it only appears to reverse the image left to right. The mirror actually reverses the image front to back. In other words, the image is facing the opposite direction relative to the object.

Section 17-2 Curved Mirrors

1. curvature
2. parallel
3. true
4. d
5. c
6. a
7. d
8. d
9. c
10. a
11. F is the focal point.
12. The dashed line is the principal axis.
13. The rays will be reflected through Point F when they are parallel to the principal axis.
14. The image will be between C and F.
15. It will be positive because the image is on the same side of the mirror as the object.
16. It will be real. Light converges at the image because d is positive.
17. The image will be reduced because the object is beyond point C.
18. The value of h_i will be lower because the object is beyond point C.
19. true
20. diverge
21. true
22. virtual
23. inverted
24. smaller
25. A convex mirror produces a virtual image because the reflected rays always diverge.
26. The image is always smaller than the object itself and thus appears to be farther away. The image actually is closer to the mirror than the object.
27. They enlarge the area, or field of view, that the observer sees. Also, the field of view looks similar from any angle of the viewer off the principal axis.
28. The focal length is negative because the focal point is behind the mirror.
29. Both have images with virtual negative image distances. They are different in that plane mirror images are the same size as the object and the same distance from the mirror as the object, whereas convex mirror images are smaller than the object and closer to the mirror than the object.

Section 17-1 Quiz

1. A rough surface has many different surfaces that reflect in many directions, so incoming parallel light rays are not reflected in parallel. A smooth surface has a single, flat surface that reflects parallel light rays in the same direction.
2. The image is virtual, is the same size as the object, has the same orientation, and is the same distance from the mirror as the object.
3. $\theta_{\text{normal}} = 90.0° - \theta_i$
   $= 90.0° - 47° = 43°$
4. The image is 2.5 m behind the mirror and is 1.5 m tall.
   $d_i = d_o$
   $d_i = 2.5$ m
   $h_i = h_o$
   $h_i = 1.5$ m

Section 17-2 Quiz

1. If the object position is greater than the focal length, a real image is produced that is inverted. If the object position is less than the focal length, a virtual image is produced that is upright.
2. The image is virtual, upright, and smaller than the object. One application is the passenger-side rearview mirror in cars.
3. $$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$$
$$f = \frac{d_i d_o}{d_i + d_o}$$
$$= \frac{(30\text{ cm})(15\text{ cm})}{30\text{ cm} + 15\text{ cm}}$$
$$= 10\text{ cm}$$
4. $$\frac{h_i}{h_o} = -\frac{d_i}{d_o}$$
$$h_i = -\frac{d_i h_o}{d_o}$$
$$= -\frac{(15\text{ cm})(0.75\text{ m})}{30\text{ cm}}$$
$$= -0.4\text{ m}$$

Chapter 17 Reinforcement

Finding the Image in a Concave Mirror

1. One ray is drawn from the top of the object parallel to the principal axis and reflects through the focal point. Another ray is drawn from the top of the object through the focal point and reflects back parallel to the principal axis. The point where these rays meet indicates the location of the image.
2. The height of the image can be determined.
3. An image actually is formed by many rays from all parts of the object.
4. The image is inverted, real, and smaller than the object.
5. The image is inverted, real, and larger than the object.

Chapter 17 Enrichment

Testing the Law of Reflection

1. Possible answer: If I shine a flashlight at a mirror on the wall at any angle, the beam of light will reflect off the mirror at the same angle.
2. Possible answer: Fold two index cards to form small "tents." Place the tents about 1 m apart and 1 m from a wall. Place the flashlight near one tent. Use the protractor, the tent, and the law of reflection to predict the path the light from the flashlight must follow in order to hit a mirror placed on the wall and then reflect to the other tent if the law of reflection is true. Use chalk to lightly mark the target point of reflection on the wall. Tape a small mirror to the wall at that point. Shine the flashlight from the first tent toward the mirror. Observe the path of the light and repeat twice. Then repeat the experiment for two other angles, with three trials for each angle.
3. Answers will vary. A success rate of 90% or more is likely.
4. Variables include the ability to hit the mirror accurately and any dispersion (spreading) of the light beam.
5. The light beam travels in a straight line regardless of the distance traveled. Thus, for all practical purposes, the law of reflection applies in all cases.

Transparency 17-1 Worksheet

Law of Reflection

1. It is an imaginary line perpendicular to the surface of the mirror.
2. It is the angle between the incident ray and the normal.
3. It is the angle between the reflected ray and the normal.
4. The angle that a reflected ray makes as measured from the normal to a reflective surface equals the angle that the incident ray makes as measured from the same normal.

5. 30°
6. The reflection of light is planar (two-dimensional).
7. No. It could be either specular or diffuse reflection. In order to determine the type of reflection, you would need to observe several different rays reflecting. If all of the rays reflect in parallel, it is specular reflection. If they all reflect in different directions, it is diffuse reflection.

Transparency 17-2 Worksheet

Image Formation by Mirrors

1. It is a concave mirror.
2. C is the center of curvature. F is the focal point.
3. The light is focused at the focal point.
4. It gets larger and farther from the mirror. It is a real image.
5. Project them on a screen, or position your eye where the image should be.
6. They are equal in size when the object is at C, the center of curvature.
7. The image is virtual, enlarged, upright, and on the opposite side of the mirror as the object.
8. It would work well as a magnifying mirror. You would have to be between the mirror and its focal point.
9. Place a light source at the focal point of the mirror so that parallel rays are reflected from the surface.

Transparency 17-3 Worksheet

Image Formation by Curved Mirrors

1. It is the principal axis.
2. They converge and form an image.
3. It is a real image.
4. Place your eye or a screen at the image position. If the image is real it will be visible or appear on the screen.
5. They diverge.
6. They indicate where light rays appear to the eye to form an image, but the light rays do not actually go behind the mirror.
7. It is a virtual image.
8. Place your eye or a screen at the image position. If the image is virtual, it will not be visible and will not appear on the screen.
9. Divide the image height by the object height, or divide the negative of the image distance by the object distance.

Chapter 17 Chapter Assessment

Understanding Physics Concepts

1. c
2. b
3. d
4. b
5. equal to
6. concave
7. true
8. true
9. upright
10. true
11. A narrow beam that is parallel to the principal axis of a spherical concave mirror is reflected from the mirror and passes through the focal point of the mirror.
12. A narrow beam that passes through the focal point of a concave mirror is reflected from the mirror parallel to the principal axis of the mirror.
13. Both types of mirror are curved. The reflective surface of a concave mirror is curved inward, and the reflective surface of a convex mirror is curved outward. Light rays that enter parallel to the principal axis of a spherical concave mirror pass through the focal point. Objects that are much farther from the mirror than the focal point produce images that are real, inverted, and reduced relative to the objects. Objects between the focal point and the mirror produce images that are virtual, upright, and enlarged relative to the objects. Convex mirrors always produce images that are virtual, erect, and reduced relative to the objects.

14. When parallel light rays strike a rough surface, they reflect in many directions, causing diffuse reflection. When parallel rays of light strike a flat, very smooth surface, they reflect in parallel, causing specular reflection.

15. It makes images seem farther away.

Thinking Critically

1. $\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$

$d_i = \frac{fd_o}{d_o - f}$

$= \frac{(11.0\text{ cm})(32.0\text{ cm})}{32.0\text{ cm} - 11.0\text{ cm}}$

$= 16.8\text{ cm}$

2. $\frac{h_i}{h_o} = -\frac{d_i}{d_o}$

$h_i = -\frac{h_o d_i}{d_o}$

$= -\frac{(2.50\text{ cm})(16.8\text{ cm})}{32.0\text{ cm}}$

$= -1.31\text{ cm}$

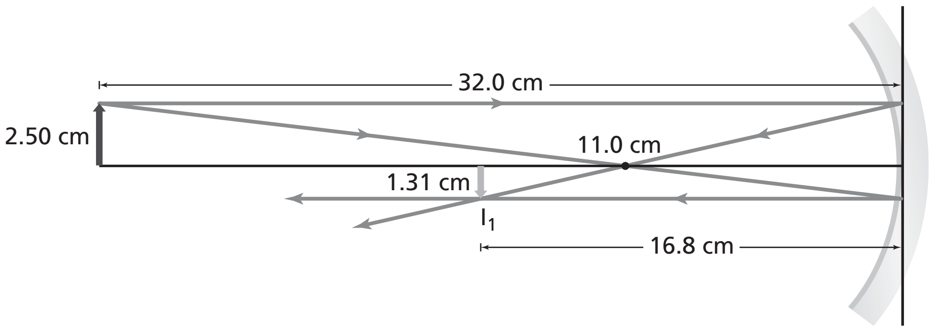
The image is 1.31 cm tall. The negative sign indicates that the image is inverted. See art below.

3. $m = -\frac{h_i}{h_o}$

$= -\frac{1.31\text{ cm}}{2.50\text{ cm}}$

$= -0.524$

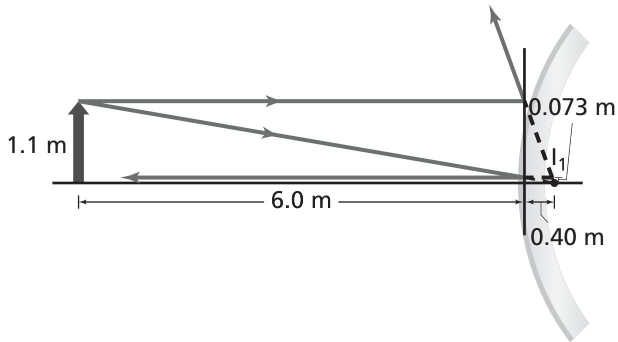
4. The image is real because the image position is positive, which means that the image is in front of the mirror.



5. $h_i = -\frac{h_o d_i}{d_o}$

$= -\frac{(1.1\text{ m})(-0.40\text{ m})}{6.0\text{ m}}$

$= 0.073\text{ m}$



6. $m = \frac{h_i}{h_o}$

$= \frac{0.073\text{ m}}{1.1\text{ m}}$

$= 0.066$

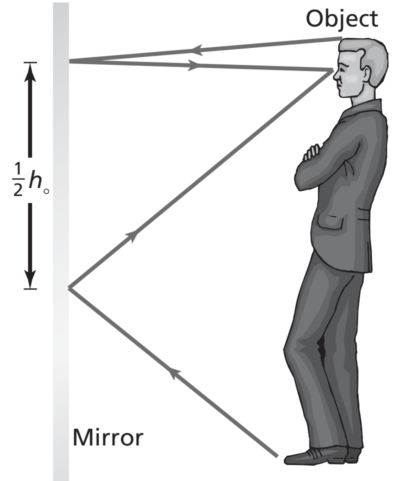
7. $\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$

$f = \frac{d_i d_o}{d_i + d_o}$

$= \frac{(6.0\text{ m})(-0.40\text{ m})}{6.0\text{ m} + 0.40\text{ m}}$

$= -0.38\text{ m}$

8. Yes, it is possible. A person will see the top of his or her head with a ray that leaves the head, hits the mirror, and is reflected into his or her eyes. A person will also see the tips of his or her toes with a ray that leaves the toes, hits the mirror, and is reflected into his eyes. The careful drawing of a ray diagram shows that the length of mirror necessary is exactly one-half of the height of the person.



9. $$d_i = \frac{fd_o}{d_o - f} = \frac{(-0.50\text{ m})(5.0\text{ m})}{5.0\text{ m} - (-0.50\text{ m})} = -0.45\text{ m}$$

$$h_o = -\frac{d_o h_i}{d_i} = -\frac{(5.0\text{ m})(0.18\text{ m})}{0.45\text{ m}} = 2.0\text{ m}$$

10. It puts the same amount of light into a smaller area.

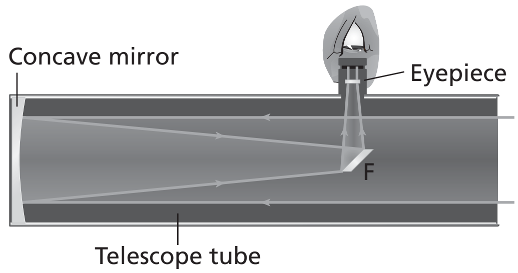
Applying Physics Knowledge

1. Only a real image can be projected onto a screen because a real image is formed by the converging of actual light rays. A virtual image is formed by the diverging of light rays, making the light rays appear to come from an image that is not actually there.

2. It is a mirror image of the word "AMBULANCE." The letters are painted this way so that motorists who see the vehicle in their rear-view mirrors will be able to read the word "AMBULANCE," realize it is an emergency vehicle, and move out of the way.

3. The mirrors are large and convex. Because they are convex, they produce reduced virtual images. However, they reflect an enlarged field of view, allowing a large area of the store to be visible in one mirror.

4. Possible answer: Use a large concave mirror to collect the light and focus it at a point. Place a small plane mirror at the focal point at a 45° angle to the principal axis to deflect the light to the point next to the telescope.



5. $$-\frac{d_i}{d_o} = \frac{h_i}{h_o}$$

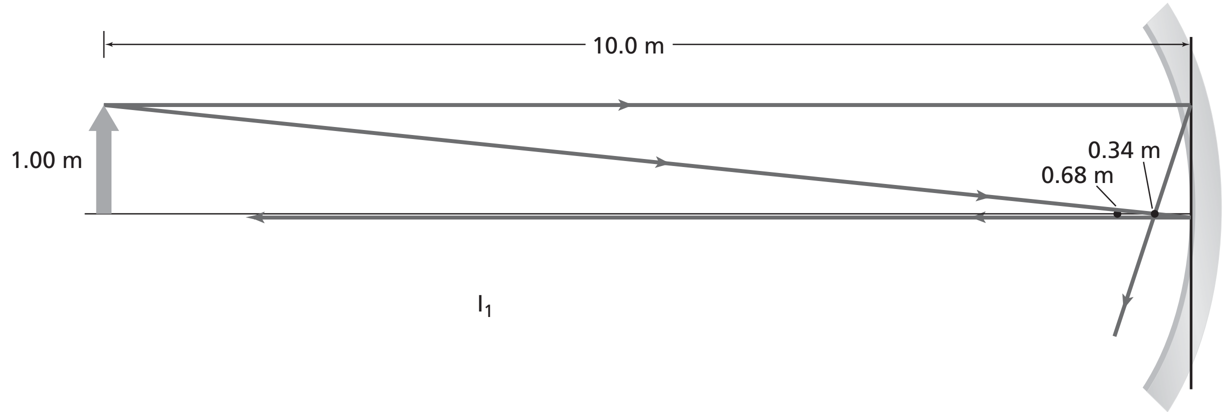
$$d_i = -\frac{d_o h_i}{h_o} = -\frac{(10.0\text{ m})(-0.035\text{ m})}{1.00\text{ m}} = 0.35\text{ m}$$

$$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$$

$$f = \frac{d_i d_o}{d_i + d_o} = \frac{(10.0\text{ m})(0.35\text{ m})}{10.0\text{ m} + 0.35\text{ m}} = 0.34\text{ m}$$

$$r = 2f = 2(0.34\text{ m}) = 0.68\text{ m}$$

See art at top of next page.



6. $f = -\frac{r}{2}$

$= -\frac{0.80\text{ m}}{2}$

$= -0.40\text{ m}$

$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$

$d_i = \frac{fd_o}{d_o - f}$

$= \frac{(-0.40\text{ m})(4.6\text{ m})}{4.6\text{ m} - (-0.40\text{ m})}$

$= -0.37\text{ m}$

The negative value indicates a virtual image.

$\frac{h_i}{h_o} = -\frac{d_i}{d_o}$

$h_i = -\frac{h_o d_i}{d_o}$

$= -\frac{(2.0\text{ m})(-0.37\text{ m})}{4.6\text{ m}}$

$= 0.16\text{ m}$

The positive value indicates that the image is upright.

7. A concave mirror should be used.

$m = 4 = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$

$d_i = -4(12.0\text{ mm})$

$= 48.0\text{ mm}$

$f = \frac{d_i d_o}{d_i + d_o}$

$= \frac{(-48.0\text{ mm})(12.0\text{ mm})}{-48.0\text{ mm} + 12.0\text{ mm}}$

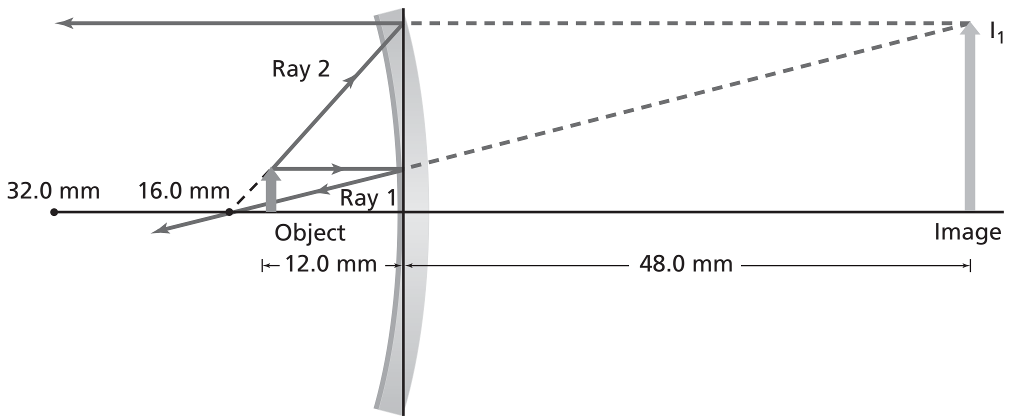
$= -16.0\text{ mm}$

$r = 2f$

$= 2(16.0\text{ mm})$

$= 32.0\text{ mm}$

See art below.



Chapter 18 Answer Key

Mini Lab Worksheet

Analyze and Conclude

1. Any portion of the lens will form a complete image.
2. The more the lens is masked, the dimmer the image becomes.

Physics Lab Worksheet

Sample Data

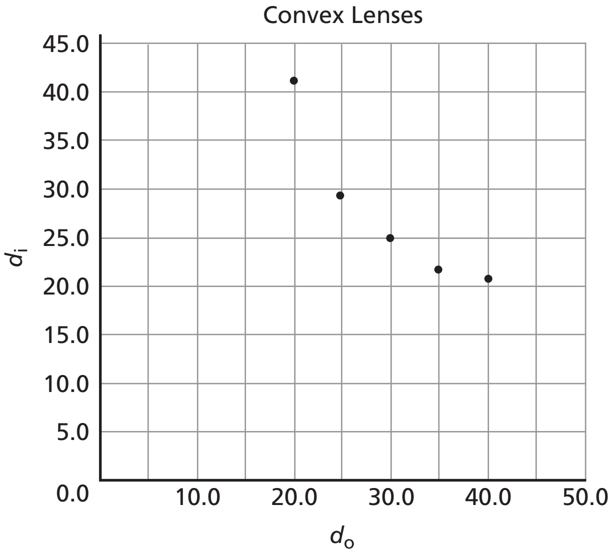
Trial	d_o (cm)	d_i (cm)
1	40.0	20.5
2	30.0	25.0
3	20.0	41.7
4	25.0	29.2
5	35.0	22.1

Calculation Table

Trial	$\frac{1}{d_o}$ (cm^{-1})	$\frac{1}{d_i}$ (cm^{-1})	$\frac{1}{d_o}+\frac{1}{d_i}$ (cm^{-1})	f (cm)
1	0.025	0.049	0.074	13.6
2	0.033	0.040	0.073	13.6
3	0.050	0.024	0.074	13.5
4	0.040	0.034	0.074	13.5
5	0.029	0.045	0.074	13.5

Analyze

1. See sample data.



2. Answers will vary. See calculation table for sample answer.
3. Answers will vary. See calculation table for sample answer.

Conclude and Apply

1. There is an inverse relationship between d_o and d_i. As one gets bigger, the other gets smaller.
2. Answers will vary. Sample answer: There is about a 3% error between the calculated value and the actual value. The accuracy is fairly good.
3. Answers will vary. Sample answer: The calculations of focal length were very precise. All of the lengths were within 0.1 cm of each other.
4. This is the approximate range for finding the focal length. If the lens is closer than the focal length you cannot get an image because it is virtual. Also, beyond a certain point, objects can be considered infinitely far away.

Going Further

1. d_o is more precise, because the lens position is fixed on the meterstick, while d_i is subject to interpretation: When is the image best in focus?
2. Uncertainty in measurement comes from the limitations of the tools used and the people doing the measuring. To make d_i more accurate, students should make sure the lenses are not dirty or scratched. They should also understand the relation between proper technique and accurate results.

Real-World Physics

1. As you look at an object that is farther away, you will need to move the lens closer to your eye.
2. The image on your retina is much smaller than the actual object, and it is upside down.

Chapter 18 Study Guide

Vocabulary Review

1. total internal reflection
2. dispersion
3. farsightedness
4. Snell's law of refraction
5. lens
6. index of refraction
7. nearsightedness
8. critical angle
9. thin lens equation
10. concave lens
11. convex lens
12. chromatic aberration
13. achromatic lens

Section 18-1 Refraction of Light

1. normal
2. does
3. Refraction
4. true
5. g
6. f
7. c
8. d
9. b
10. a
11. e
12. B is the incident ray. The direction is shown by the arrow.
13. A is the boundary.
14. C is the normal. It is at right angles to the boundary.
15. D is the refracted ray. It is bent as it enters the second medium.
16. F is the angle of incidence. It is the angle between the incident ray and the normal.
17. G is the angle of refraction. It is the angle between the refracted ray and the normal.
18. true
19. true
20. false
21. false
22. false
23. false
24. true
25. true
26. b
27. c
28. d
29. a
30. b
31. c
32. d

Section 18-2 Convex and Concave Lenses

1. Convex lenses are also called converging lenses because they refract parallel rays so that they meet at a point. Concave lenses are also called diverging lenses because rays passing through them spread out.
2. It is a model that assumes that all refraction occurs at a plane that passes through the center of the lens.
3. c
4. d
5. a
6. b
7. b

Section 18-3 Applications of Lenses

1. The shape of the lens determines the focal length of the eye and thus the distance at which objects are in focus.
2. Nearsightedness is a condition in which the focal length of the eye is too short to focus light on the retina. It is corrected using concave lenses.
3. Farsightedness is a condition in which the focal length of the eye is too long and images are formed past the retina. It is corrected using convex lenses.
4. Muscles surrounding the lens change the shape of the lens by contracting and relaxing. This process is called accommodation.
5. A convex lens produces a virtual image that is farther from the eye than the associated object. This image then becomes the object for the eye lens and can be focused on the retina, thus correcting a defect in vision.

Section 18-1 Quiz

1. $n_1 \sin \theta_1 = n_2 \sin \theta_2$ The product of the index of refraction of the first medium and the sine of the angle of incidence is equal to the product of the index of refraction of the second medium and the sine of the angle of refraction.
2. The index of refraction of a medium is equal to the speed of light in vacuum divided by the speed of light in the medium, $n = \frac{c}{v}$.
3. The critical angle is the angle of incidence at which the refracted light ray lies along the boundary of two media. Total internal reflection occurs when the angle of incidence exceeds the critical angle.
4. $n_1 \sin \theta_1 = n_2 \sin \theta_2$

$$\theta_2 = \sin^{-1}\left(\frac{n_1}{n_2} \sin \theta_1\right)$$
$$= \sin^{-1}\left(\frac{1.36}{2.42} \sin 42°\right)$$
$$= 22°$$

5. $n = \frac{c}{v}$

$$v = \frac{c}{n}$$
$$= \frac{3.00\times10^8 \text{ m/s}}{1.52}$$
$$= 1.97\times10^8 \text{ m/s}$$

6. $\sin \theta_c = \frac{n_2}{n_1}$

$$\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$$
$$= \sin^{-1}\left(\frac{1.33}{1.62}\right)$$
$$= 55.2°$$

Section 18-2 Quiz

1. When the distance between the object and the lens is greater than twice the focal length the image is real, inverted, and smaller than the object. When the distance between the object and the lens is less than twice the focal length but more than the focal length, the image is real, inverted, and larger than the object. When the object is between the lens and the focal point the image is virtual, upright, and larger than the object.
2. A concave lens always produces an image that is virtual, upright, and smaller than the object.
3. Spherical aberration is caused by rays passing through the edges of a lens focusing at a different position than rays passing through the center. Chromatic aberration is caused by different wavelengths of light being bent at slightly different angles.
4. $\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$

$$f = \frac{d_i d_o}{d_i + d_o}$$
$$= \frac{(0.5 \text{ m})(2 \text{ m})}{0.5 \text{ m} + 2 \text{ m}}$$
$$= 0.4 \text{ m}$$

5. $m = \frac{h_i}{h_o}$

$= \frac{-8\text{ cm}}{4\text{ cm}}$

$= -2$

Section 18-3 Quiz

1. Muscles surrounding the lens relax or contract, changing the shape of the lens. This changes the focal length of the eye. When the muscles relax the focal length increases, focusing the image of distant objects on the retina. When the muscles contract the focal length decreases, focusing the image of closer objects on the retina.

2. Nearsightedness is caused when the focal length of the eye is too short to focus light on the retina. Images are formed in front of the retina. Farsightedness is caused when the focal length of the eye is too long and images are formed behind the retina.

3. Parallel rays of light from an object enter a convex objective lens and are focused as a real inverted image. This image is then used as the object for a convex eyepiece lens, which produces a larger virtual image.

4. They are similar in that each side of the binoculars is like a small telescope. They are different in that binoculars use prisms to produce upright images. Binoculars also produce separated images in each eye, giving a three-dimensional view.

5. Microscopes also have objective and eyepiece lenses and form enlarged virtual images. Unlike telescopes, microscopes are used to view very small objects rather than distant ones.

Reinforcement

1. The eyeball is longer than normal, which, all other factors being equal, would cause images of objects to fall in front of the retina.

2. The eyeball is shorter than normal, which, all other factors being equal, would cause images of objects to fall behind the retina.

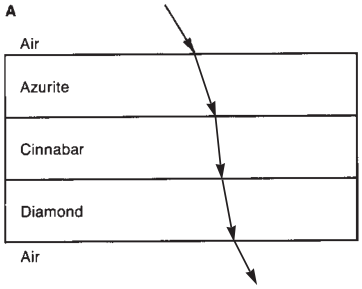
3. The position of an image projected within the eye would be moved toward the front of the eye and in front of the retina; the image would be blurred.

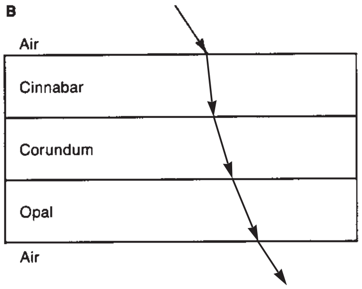
4. The position of an image projected within the eye would be moved away from the front of the eye and behind the retina; the image would be blurred.

5. The position of an image projected within the eye would be moved away from the front of the eye and more distant from the retina; the image would be more severely blurred.

6. The position of an image projected within the eye would be moved away from the front of the eye. If this change placed the image on the retina, normal vision would be restored.

Enrichment





For part A:

$$n_2 \sin \theta_2 = n_1 \sin \theta_1$$

$$\theta_2 = \sin^{-1}\left(\frac{n_1}{n_2} \sin \theta_1\right)$$

$$\text{azurite: } \theta_2 = \sin^{-1}\left(\frac{1.00}{1.76} \sin 40.0°\right) = 21.4°$$

$$\text{cinnabar: } \theta_2 = \sin^{-1}\left(\frac{1.76}{2.81} \sin 21.4°\right) = 13.2°$$

$$\text{diamond: } \theta_2 = \sin^{-1}\left(\frac{2.81}{2.42} \sin 13.2°\right) = 15.4°$$

$$\text{air: } \theta_2 = \sin^{-1}\left(\frac{2.42}{1.00} \sin 15.4°\right) = 40.0°$$

For part B:

$$n_2 \sin \theta_2 = n_1 \sin \theta_1$$

$$\theta_2 = \sin^{-1}\left(\frac{n_1}{n_2} \sin \theta_1\right)$$

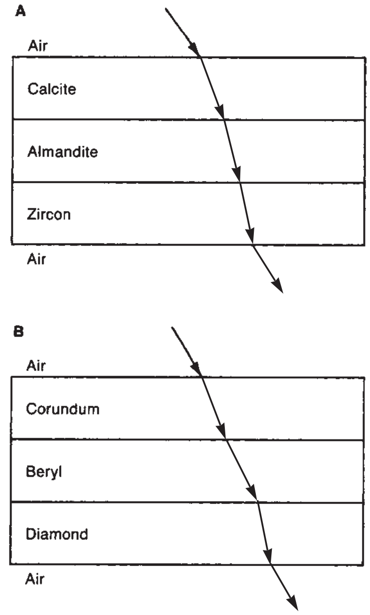
$$\text{cinnabar: } \theta_2 = \sin^{-1}\left(\frac{1.00}{2.81} \sin 40.0°\right) = 13.2°$$

$$\text{corundum: } \theta_2 = \sin^{-1}\left(\frac{2.81}{1.77} \sin 13.2°\right) = 21.3°$$

$$\text{opal: } \theta_2 = \sin^{-1}\left(\frac{1.77}{1.44} \sin 21.3°\right) = 26.5°$$

$$\text{air: } \theta_2 = \sin^{-1}\left(\frac{1.44}{1.00} \sin 26.5°\right) = 40.0°$$

1. Light bends toward the normal when it enters a medium with a higher index of refraction. Light bends away from the normal when it enters a medium with a lower index of refraction.
2. The speed of light is the highest in opal. It has the lowest index of refraction. The speed of light varies inversely with the index of refraction.
3. The speed of light is the lowest in cinnabar. It has the highest index of refraction.

4. 

   a. Light bends toward the normal as it passes through each boundary, until it enters the air, when it bends away from the normal.
   b. Light bends towards the normal, away from the normal, towards the normal, and away from the normal.
5. Light bends the most at the air-cinnabar boundary. The difference in indices of refraction is greatest at this boundary.
6. Light bends the least at the almandite-zircon boundary. The difference in indices of refraction is lowest at this boundary.
7. If the index of refraction were the same on both sides of a boundary, light would neither bend toward nor away from the normal.

Transparency Worksheet 18-1

Index of Refraction

1. They represent the paths of light rays.
2. The angle of incidence, (θ_1), is 60.0º.
3. The angle of refraction, (θ_2), is 34.5º.
4. The angle is 34.5°.
5. The angle is 60.0°.
6. Glass should have a greater index of refraction than water because the angle of refraction for glass is smaller than the angle of refraction for water ($n_1 \sin \theta_1 = n_2 \sin \theta_2$).
7. $n_r = n_i \sin \theta_i / \sin \theta_r$
   $= 1.00 \sin 60.0° / \sin 34.5°$
   $= 1.53$
8. $n_r = n_i \sin \theta_i / \sin \theta_r$
   $= 1.00 \sin 60.0° / \sin 40.6°$
   $= 1.33$
9. It travels faster through water.

Transparency Worksheet 18-2

Refraction of Light and Illusions

1. He thinks that he sees a pool of water in the road. He actually sees the sky in a mirage.
2. Light rays from the sky are bent upward by a layer of hot air just above the ground and sent toward the observer.
3. He thinks he sees an upside-down ship in the sky. He actually sees the real ship in a mirage.
4. Light rays from the sky are bent downward by a layer of warm air just above the cool air above the ocean surface.
5. Light rays from the pencil are refracted as they pass from water into air, making it appear as if part of the pencil were in a different location.
6. Light rays from the fish are refracted as they pass from water into air, making it appear as if the fish were closer to the surface.

Transparency Worksheet 18-3

Images Formation by Curved Lenses

1. Figure a is a convex, or converging, lens. Figure b is a concave, or diverging, lens.
2. F is the focal point.
3. The light is focused at the focal point.
4. It gets larger and farther from the lens.
5. Project them on a screen or position your eye where the image should be.
6. They are equal in size when the object is at 2F.

7. The image is virtual, enlarged, upright, and on the same side of the lens as the object.
8. It causes them to diverge.
9. A concave lens always forms a virtual image that is upright and smaller than the object.

Transparency Worksheet 18-4

Nearsightedness, Farsightedness, and Lenses

1. The lens of the eye causes the incoming light rays to converge at, or focus on, the retina at the back of the eye.
2. The light is coming from the right. The lens is the elliptical structure at the right where light rays are entering the eye. The retina is shown at the left end of the diagram.
3. The light is focused in front of the retina rather than on it.
4. The focal length of the eye is shorter than the distance from the lens to the retina of the eye.
5. A concave lens is used. It is a diverging lens. The light rays focus farther from the lens of the eye, producing a clear image on the retina.
6. The light is focused behind the retina rather than on it.
7. The focal length of the eye is longer than the distance from the lens to the retina of the eye.
8. A convex lens is used. It is a converging lens. The light rays focus closer to the lens of the eye, producing a clear image on the retina.

Chapter Assessment

Understanding Physics Concepts

1. c
2. c
3. b
4. c
5. a
6. a
7. a
8. c
9. a
10. true
11. negative
12. slower
13. true
14. smaller
15. larger
16. true
17. refracted
18. complete
19. true
20. observer
21. true
22. higher, true

Thinking Critically

1. The sine of the angle of incidence divided by the sine of the angle of refraction is equal to a constant called the index of refraction of the medium.
2. Total internal reflection occurs when light passes from a medium into a medium with a lower index of refraction at an angle of incidence so great that no ray is refracted. This incident angle is the critical angle—all light striking the boundary at an angle of incidence greater than the critical angle is internally reflected.
3. The angle of refraction is greater than the angle of incidence. As the angle of incidence increases, the angle of refraction increases until it reaches 90°. Further increases in the angle of incidence produce total internal reflection, and there are no more refracted rays.
4. A convex lens is thicker at the center than it is at the edges and refracts light rays that are parallel to the principal axis so that they converge. A concave lens is thinner at the center than at the edges and refracts light rays so that they diverge.
5. If the object is more than twice the focal length away, the image is real, inverted, and reduced. If the object is between the focal point and the lens, the image is virtual, erect, and enlarged.

6. $n_2 \sin \theta_2 = n_1 \sin \theta_1$

$$\theta_2 = \sin^{-1}\left(\frac{n_1}{n_2} \sin \theta_1\right)$$
$$= \sin^{-1}\left(\frac{1.00}{1.54} \sin 35°\right)$$
$$= 22°$$

7. $n_2 \sin \theta_2 = n_1 \sin \theta_1$

$$n_2 = n_1 \frac{\sin \theta_1}{\sin \theta_2}$$
$$= (1.00)\left(\frac{\sin 55°}{\sin 35°}\right)$$
$$= 1.4$$

8. $n_2 \sin \theta_2 = n_1 \sin \theta_1$

$$\theta_2 = \sin^{-1}\left(\frac{n_1}{n_2} \sin \theta_1\right)$$
$$= \sin^{-1}\left(\frac{1.33}{2.42} \sin 53°\right)$$
$$= 26°$$

Applying Physics Knowledge

1. $n = \frac{c}{v}$

$$v = \frac{c}{n}$$
$$= \frac{3.00\times10^8 \text{ m/s}}{1.54}$$
$$= 1.95\times10^8 \text{ m/s}$$

2. $\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$

$$d_i = \frac{fd_o}{d_o - f}$$
$$= \frac{(6.00 \text{ cm})(5.00 \text{ cm})}{6.00 \text{ cm} - 5.00 \text{ cm}}$$
$$= -30.0 \text{ cm}$$

The image is on the same side of the lens as the object and is virtual.

3. $\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$

$$f = \frac{d_i d_o}{d_i - d_o}$$
$$= \frac{(-10.0 \text{ cm})(35.00 \text{ cm})}{-10.00 \text{ cm} + 35.00}$$
$$= -14.0 \text{ cm}$$

4. $n_2 \sin \theta_2 = n_1 \sin \theta_1$

$$\theta_2 = \sin^{-1}\left(\frac{n_1}{n_2} \sin \theta_1\right)$$

For the red light:

$$\theta_{2,\text{red}} = \sin^{-1}\left(\frac{1.00}{1.57} \sin 65.0°\right)$$
$$= 35.3°$$

For the violet light:

$$\theta_{2,\text{violet}} = \sin^{-1}\left(\frac{1.00}{1.59} \sin 65.0°\right)$$
$$= 34.8°$$

The angle between:

$\theta_{2,\text{red}} - \theta_{2,\text{violet}} = 35.3° - 34.8° = 0.5°$

5. For the red light:

$$\theta_{2,\text{red}} = \sin^{-1}\left(\frac{1.00}{1.57} \sin 60.0°\right)$$
$$= 33.5°$$

For the violet light:

$$\theta_{2,\text{violet}} = \sin^{-1}\left(\frac{1.00}{1.59} \sin 60.0°\right)$$
$$= 33.0°$$

The angle between:

$\theta_{2,\text{red}} - \theta_{2,\text{violet}} = 33.5° - 33.0° = 0.5°$

The amount of dispersion is not affected.

6. a. $n_1 \sin \theta_1 = n_2 \sin \theta_2$

$$\theta_2 = \sin^{-1}\left(\frac{n_1}{n_2} \sin \theta_1\right)$$
$$= \sin^{-1}\left(\frac{1.33}{1.00} \sin 52.0°\right)$$
$$= \sin^{-1}(1.05)$$

There is no angle with a sine value greater than 1, so there is no refracted light. Total internal reflection therefore must occur.

b. By the law of reflection, the angle of reflection equals the angle of incidence, 52.0°

Chapter 19

Mini Lab Worksheet

Retinal Projection Screen

3. The spectra are easily observed with the diffraction grating, so students should not have difficulty drawing the pattern they observe. Purple/blue light is closest to the central bright line (light), while red is farthest away. The spectrum repeats multiple times on both sides of the central bright line.

Analyze and Conclude

4. purple/blue
5. red
6. Answers may vary. Two should be visible.
7. Yes. Red light has a $\lambda = 650$ nm and purple has a $\lambda = 425$ nm; thus, red should be located farther from the central bright line than purple/blue in a given spectrum.

Physics Lab Worksheet

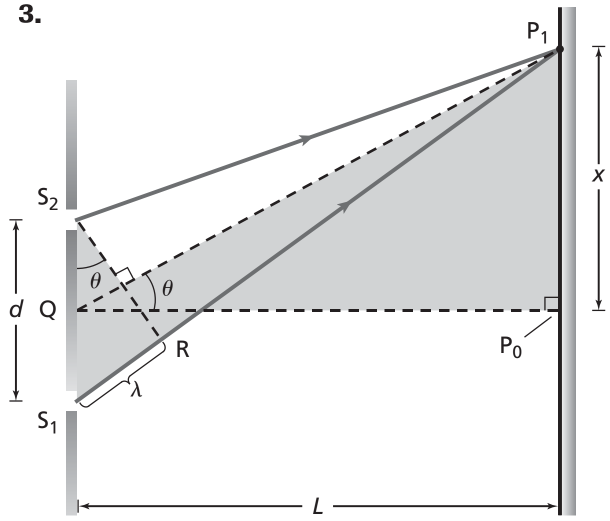
Double-Slit Interference of Light

Procedure

1. $\lambda = \frac{xd}{L}$

2. An example of a typical double-slit separation distance used in this type of experiment is 0.0190 mm, or 1.90×10^{-5} m. If d is unknown, the laser of known wavelength can be used to collect data on the interference pattern and calculate d.

3.



4. Set-up should include using the clay ball to secure the double-slit plate, using the clothes pin to stabilize the laser-pointer assuring a steady light, and the provision of a projection screen.

Procedure:

- Record the slit spacing for the two sets of slits (A, B).
- Turn on the laser and adjust the beam so it strikes the middle of the plate
- Direct the laser so that an equal amount of light passes through each of the two slits.
- Observe the double-slit interference pattern on the screen (or suitable wall). Further adjust laser (or plate) position so that the bands are distinct.
- Measure the distance from the slit slide to the wall.
- Tape a piece of paper to the wall or screen and carefully record the pattern.

- Remove your paper from the wall and turn off the laser.

  The procedure should also include measuring the distances (S_1, S_2, S_3, ...) and calculating the average (y) values for each set of bright bands on either side of the central band ($Y_1 = (1/2)S_1$, $Y_2 = (1/2)S_2$, et cetera).

  Finally, students should determine the wavelength of the laser light using the bright band equation for each average (y) value obtained.

5. Constructive interference from two slits occurs at locations, x, on either side of the central band. Using $m\lambda = \frac{x_m d}{L}$, the central bright band occurs at $m = 0$, the first-order band is $m = 1$.

Analyze

1. With greater distance from the screen, the pattern spreads out. The resulting separation of the bands may make it easier to measure x, but contrast is also reduced with distance, making some bands harder to see. Precision is a matter of finding a distance that provides band sharpness and clear separation in equal measure.
2. Answers will vary. Sample answer:
   $\lambda = xd/L$
   $= (5.5\times10^{-3}\text{ m})(2.0\times10^{-4}\text{ m})/1.83\text{ m}$
   $= 6.0\times10^{2}\text{ nm}$
3. Answers will vary. Sample answer:
   Percent error = (670 nm − 601 nm)(100)/(670 nm) = 10%

Conclude and Apply

1. Answers will vary. Sample answer: Our procedure worked. We measured the wavelength of light
2. A smaller d will increase x.
3. Green light has a smaller wavelength; therefore, x will be smaller than with red light.

Going Further

1. This is a single-slit diffraction pattern that overlays the double-slit interference pattern. It results from using slits that are much wider than 1 μm.
2. Answers will vary. Sample answer: Increase L to increase x. Use a darker room so the patterns are clearer.
3. Answers will vary. Sample answer: The least precision resulted from using a meterstick to measure x. The wavelength of the known laser gave more precision than was needed.
4. Place a single slit with a narrow slit width between the lightbulb and the double slit.

Real-World Physics

1. Daylight through a screen is generally incoherent, because it comes from many sources. If it were coherent, the slit separation distance is large enough to cause the bright bands to be too close together to be seen. For both reasons, the pattern is *washed out.*
2. Such a world would appear much less nuanced and more sharply defined—more akin to a line drawing than a soft pastel. Incoherent light, which comes from all directions, lights more evenly, whereas coherent light results in harsh contours.

Chapter 19 Study Guide

Interference and Diffraction

Vocabulary Review

1. thin-film interference
2. diffraction grating
3. diffraction pattern
4. Rayleigh criterion
5. interference fringes
6. coherent light
7. monochromatic light
8. incoherent light

Section 19-1 Interference

1. c
2. a
3. b
4. b
5. a
6. c
7. a

8. a
9. b
10. a
11. d
12. d
13. x
14. L
15. P_0
16. P_1
17. d
18. λ
19. true
20. thin-film interference
21. by constructive and destructive
22. true
23. the film thickness and the indices of refraction at both reflecting boundaries
24. $\lambda = \frac{xd}{L} = \frac{(1.86\times10^{-2}\text{ m})(2.00\times10^{-5}\text{ m})}{5.50\times10^{-1}\text{ m}}$
    $= 6.76\times10^{-7}\text{ m} = 676\text{ nm}$
25. Constructive interference with one wave inversion:
    $2d = (m + \frac{1}{2})\lambda_{\text{oil}}$
    The thinnest film has $m = 0$, and
    $\lambda_{\text{oil}} = \frac{\lambda_{\text{vacuum}}}{n_{\text{oil}}}$
    $2d = \frac{1}{2}\left(\frac{\lambda_{\text{vacuum}}}{n_{\text{oil}}}\right)$
    $d = \frac{\lambda_{\text{vacuum}}}{4n_{\text{oil}}} = \frac{442\text{ nm}}{4(1.45)} = 76.2\text{ nm}$

Section 19-2 Diffraction

1. shorter
2. true
3. Huygens' wavelets
4. multiplied by the distance to the screen divided by the width of the slit
5. diffract
6. diffraction
7. narrow
8. broad
9. colors
10. transmission
11. reflection
12. holographic
13. wavelengths
14. grating
15. angle
16. θ
17. $\frac{\lambda}{d}$
18. a
19. c
20. b
21. a
22. $2x_1 = \frac{2\lambda L}{w}$
    $= \frac{2(4.12\times10^{-7}\text{ m})(8.5\times10^{-1}\text{ m})}{3.8\times10^{-5}\text{ m}}$
    $= 1.8\times10^{-2}\text{ m} = 18\text{ mm}$
23. $\tan\theta = \frac{x}{L}$
    $\theta = \tan^{-1}\frac{x}{L} = \tan^{-1}\left(\frac{94.0\text{ cm}}{85.0\text{ cm}}\right) = 47.9°$
    $\lambda = d\sin\theta$
    $d = \frac{\lambda}{\sin\theta} = \frac{524\text{ nm}}{\sin 47.9°} = 706\text{ nm}$

Section 19-1 Quiz

1. Light that has unsynchronized wavefronts and produces no regular patterns is incoherent light. Coherent light comes from two or more wave sources and the waves combine to produce smooth wave fronts. Monochromatic light has only one wavelength and can be coherent or incoherent.
2. Light waves are diffracted by the slits and overlap, producing a pattern on a screen. In waves that are in phase, crests match crests, and the waves undergo constructive interference. Constructive interference produces the bright bands in the pattern. When the crest of one wave matches the trough of another wave, destructive interference occurs. Destructive interference produces dark bands.

3. $\lambda = \frac{xd}{L}$

$= \frac{(2.14\times10^{-2}\text{ m})(1.58\times10^{-5}\text{ m})}{0.730\text{ m}}$

$= 4.63\times10^{-7}\text{ m} = 463\text{ nm}$

4. The soap film has air on either side (lower indices of refraction), so there is only one wave inversion. Constructive interference with the thinnest film ($m = 0$):

$2d = (0 + \frac{1}{2})\frac{\lambda_{\text{vacuum}}}{n_{\text{soap}}}$

$d = \frac{\lambda_{\text{vacuum}}}{4n_{\text{soap}}} = \frac{6.33\times10^{-7}\text{ m}}{4(1.33)}$

$= 1.19\times10^{-7}\text{ m} = 119\text{ nm}$

Section 19-2 Quiz

1. Double-slit patterns contain equally spaced light and dark bands. Single-slit patterns show a wide, bright central band with dimmer, narrower bands to either side of the central band. Double-slit interference results from the interference of single-slit diffraction patterns of the two slits.

2. $2x_1 = \frac{2\lambda L}{w}$

$w = \frac{\lambda L}{x_1} = \frac{(4.83\times10^{-7}\text{ m})(9.4\times10^{-1}\text{ m})}{2.1\times10^{-2}\text{ m}}$

$= 2.2\times10^{-5}\text{ m}$

3. A grating spectroscope contains a diffraction grating and is used to measure wavelength. Light passes through the spectroscope, resulting in a pattern of narrow, equally spaced lines. The angle between the central bright line and an adjacent bright line can be used to calculate wavelength using the equation $\lambda = d \sin \theta$.

4. $x_{\text{obj}} = \frac{1.22\lambda L_{\text{obj}}}{D}$

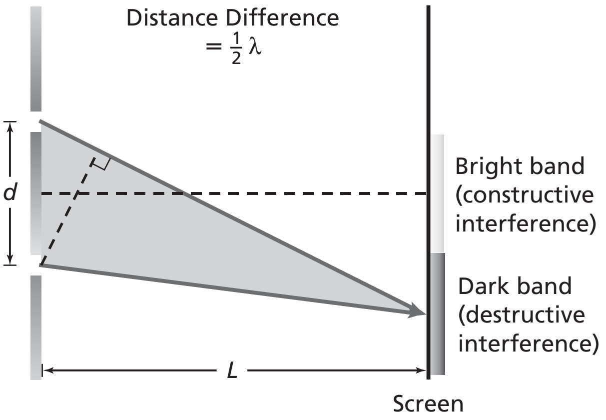
$= \frac{1.22(5.50\times10^{-7}\text{ m})(4\text{ ly})(9.46\times10^{15}\text{ m/ly})}{1.20\text{ m}}$

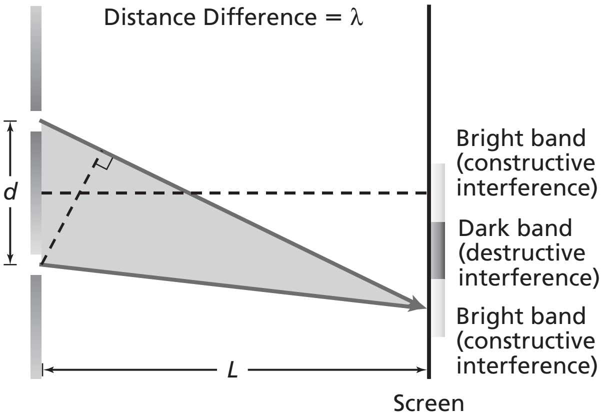
$= 2\times10^{10}\text{ m}$

Chapter 19 Reinforcement

Double-Slit Interference

1. **a.** light band; constructive interference
   b. light band; constructive interference
   c. dark band; destructive interference
2.





Chapter 19 Enrichment

1. The distances are the same.
2. All waves that reach the center of the screen are in phase, so constructive interference of these waves produce a bright band.
3. Dark bands are on either side of the central bright band.
4. Waves that reach the screen to either side of the bright band are not in phase. Dark bands are the result of this destructive interference.

5. For a bright band to be present, the waves must be in phase, and constructive interference occurs. For these conditions to exist, the difference between the lengths of the paths must be exactly one wavelength.
6. The following measurements must be made: the distance between the slits, d; the length of the path from the slits to the screen, L; and the distance between the center bright band and a bright band next to it, x.
7. $\lambda = \frac{xd}{L}$
8. Sample events:
   Set up experiment like that in the figure.
   Measure the distance between the slits and the distance from the slits to the screen.
   Shine light through the slits.
   Measure the distance between the central bright line and the adjacent bright lines.
   Use the equation $\lambda = \frac{xd}{L}$ to calculate the wavelength of the light.

Transparency 19-1 Worksheet

Destructive and Constructive Interference

1. P_1 represents the position of the first-order line, which is the location where the first bright band on either side of the central band falls on the screen.
2. P_1S_1 is one wavelength longer than P_1S_2.
3. The length is λ.
4. Measure L, d, and x (the distance between the central bright line and the first-order bright line). Then use the equation $\lambda = \frac{xd}{L}$.
5. All waves passing through the slit have approximately the same distance to travel, so their crests arrive at P_0 at the same time and interfere constructively.
6. The smaller the slit, the wider the band.
7. $x = \frac{\lambda L}{w}$

Transparency 19-2 Worksheet

Double-Slit Wave Interference

1. They are diffracted into a pattern of bright and dark bands.
2. The bands are called interference fringes.
3. The red semicircles represent the crests.
4. The dark bands represent regions of destructive interference. The bright bands represent regions of constructive interference.
5. Resulting waves of greater amplitude are represented by bright bands. Resulting waves of lesser amplitude are represented by dark bands.
6. One color of light produced the pattern.
7. The illustration would show a colored spectra instead of bright and dark bands.
8. The pattern would consist of a wide, bright central band in line with the slit with dimmer, narrower bands on either side.

Transparency 19-3 Worksheet

Thin-Film Interference

1. The spectrum of colors is the result of the constructive and destructive interference of light waves due to reflection in a thin film, such as that produced by a soap bubble or formed by a thin wedge of air (photograph on right) or that produced by a thin film of oil on a puddle of water or formed by glass plates placed flat together (photograph at bottom).
2. The thickness of the film varies. As the light wave from the flashlight strikes the film, each color is reinforced where the soap film thickness is $\frac{\lambda}{4}, \frac{3\lambda}{4}, \frac{5\lambda}{4}$ of the wavelength. Bands occur when the path difference is an integer multiple of the wavelength of the light, such as λ, 2λ, 3λ. Because each color has a different wavelength, you see a series of color bands reflected.
3. The light that is reflected is coherent. When a light wave strikes the thin film, it is partially reflected and partially transmitted. These reflected and transmitted waves have the same frequency as the source light. The transmitted wave travels through the film to

the back surface where it is again partially reflected. Splitting each light wave from an incoherent source into a matched pair of waves means that the reflected light from a thin film is coherent.

4. The photograph at the bottom shows swirls of color; irregular, thin pockets of air trapped between glass plates cause the irregular interference pattern we see.

Transparency 19-4 Worksheet

Diffraction Gratings and Light

1. Light passing through a diffraction grating behaves more like light passing through a single slit. The diffraction pattern formed is an overlap of single-slit diffraction patterns.

2. The grating shown is a transmission grating because light passes through the grating and is not reflected by it.

3. Wavelength can be measured.

4. $d = \frac{1}{5000}\ \text{cm} = 2^{-4}\ \text{cm} = 2\times10^{-6}\ \text{m}$

5. $\lambda = d \sin\theta$
$= (2\times10^{-6}\ \text{m})(\sin 17°)$
$= 6\times10^{-7}\ \text{m}$

6. 600 nm

Chapter 19 Chapter Assessment

Understanding Physics Concepts

1. g
2. h
3. d
4. b
5. a
6. f
7. e
8. c
9. D
10. L_{obj}
11. 1.22
12. L
13. x_{obj}
14. x_1
15. λ
16. c
17. b
18. d
19. d
20. a
21. c
22. b
23. d
24. d
25. c
26. b
27. b
28. b
29. d
30. b
31. d
32. a

Thinking Critically

1. Compare the pattern to the standard patterns produced in each setup. For double-slit interference, the pattern is a central bright band and lighter side bands of the color of monochromatic light that is used, separated by dark bands. The bright bands are equally spaced. If white light is used, the central band is white, and the side bands show spectra. Using a single slit, a wide, bright center band forms with narrower, dimmer bands to the side. A diffraction grating produces narrow, equally spaced bright lines.

2. The pattern is no longer centered but shifted to the same side as the slit with the glass. The glass delays the wavefront at the slit and the light reaches the screen slightly behind the light from the unobstructed slit. The distance of the shift depends upon the thickness of the glass.

3. The wavelength of yellow light is longer than the wavelength of green light. Because the difference in path lengths to the central bright band and the bright band next to it must equal one wavelength, the bright bands from the green light would be closer together.

4. The wavelength of sound is much longer than the wavelength of light. The slits would have to be much wider, as would the distance to the screen. A different method would have to be used to detect interference patterns, as no light would be seen.

Applying Physics Knowledge

1. $\lambda = \frac{xd}{L}$

$x = \frac{\lambda L}{d} = \frac{(4.5\times10^{-7}\text{ m})(0.650\text{ m})}{1.72\times10^{-5}\text{ m}}$

$= 1.7\times10^{-2}\text{ m} = 17\text{ mm}$

2. $\lambda = \frac{xd}{L} = \frac{(4.42\times10^{-2}\text{ m})(1.95\times10^{-5}\text{ m})}{1.25\text{ m}}$

$= 6.90\times10^{-7}\text{ m} = 6.90\times10^{-2}\text{ nm}$

3. $\lambda = \frac{xd}{L}$

$x = \frac{\lambda L}{d} = \frac{(5.7\times10^{-7}\text{ m})(0.800\text{ m})}{1.90\times10^{-5}\text{ m}}$

$= 2.4\times10^{-2}\text{ m} = 24\text{ mm}$

4. $2x_1 = \frac{2\lambda L}{w} = \frac{2(5.7\times10^{-7}\text{ m})(0.800\text{ m})}{9.00\times10^{-5}\text{ m}}$

$= 1.0\times10^{-2}\text{ m} = 1.0\times10^{1}\text{ mm}$

5. The starting with the first wave inversion at $m = 0$, and $\lambda_{oil} = \frac{\lambda_{vacuum}}{n_{oil}}$

$2d = \left(m + \frac{1}{2}\right)\lambda_{oil}$

$2d = \frac{1}{2}\left(\frac{\lambda_{vacuum}}{n_{oil}}\right)$

$\lambda = 4dn_{oil} = 4(90\text{ nm})(1.45) = 500\text{ nm}$, which corresponds to green light.

Continuing with the second wave inversion, $m = 1$

$2d = \frac{3}{2}\left(\frac{\lambda_{vacuum}}{n_{oil}}\right)$

$\lambda = \frac{4}{3}dn_{oil} = \frac{4}{3}(90\text{ nm})(1.45) = 200\text{ nm}$,

which is already below the visible spectrum. Any higher-order reflection will not be visible.

6. $d = \frac{1\text{ cm}}{6.00\times10^{3}\text{ lines}} = 1.67\times10^{-6}\text{ m}$

$\theta = \tan^{1}\left(\frac{0.129\text{ m}}{0.400\text{ m}}\right)$

$\theta = 17.9°$

$\lambda = d\sin\theta$

$\lambda = (1.67\times10^{-6}\text{ m})(\sin 17.9°)$

$\lambda = 5.13\times10^{-7}\text{ m} = 513\text{ nm}$

7. $d = \frac{1\text{ cm}}{1.00\times10^{4}\text{ lines}} = 1.00\times10^{-6}\text{ m}$

$\lambda = d\sin\theta$

$\theta = \sin^{-1}\left(\frac{\lambda}{d}\right) = \sin^{-1}\left(\frac{4\times10^{-9}\text{ m}}{1.00\times10^{-6}\text{ m}}\right)$

$= 20°$

8. $D = \frac{1.22\lambda L_{obj}}{x_{obj}}$

$= \frac{1.22(5.5\times10^{-7}\text{ m})(10.5\text{ ly})(9.46\times10^{15}\text{ m/ly})}{1.50\times10^{11}\text{ m}}$

$= 0.44\text{ m} = 44\text{ cm}$

Chapter 20

Mini Lab

Analyze and Conclude

4. Students should indicate that the leaves of the electroscope spread apart when a charged object is brought near the electroscope and when the charged object is touched to the knob of the electroscope. Verify that the students' diagrams reflect these observations.

5. In the first part (balloon near a neutral electroscope), the negative charges on the balloon repel electrons onto the leaves of the electroscope. The electroscope hasn't gained or lost charges, but a negative charge has been induced in the leaves. When the balloon is touched to the electroscope, negative charges transfer from the balloon to the electroscope, giving the electroscope a net negative charge.

6. If the wool had been used, electrons would have been attracted to the knob of the electroscope, and the leaves would have spread because of an induced positive charge in the leaves. If the wool were touched to the electroscope, electrons would have been attracted, leaving the electroscope with a net positive charge.

Physics Lab

Sample Data

Answers will vary, depending on materials used. Several examples are included in the sample data table. See below.

Analyze

1. Yes, the force is strong enough to move the suspended ruler.
2. A sample drawing could show a suspended ruler with negative charges drawn on it being repelled by a rubber rod that also has negative charges drawn on it.
3. Materials that hold a charge are the good insulators, such as plastic and rubber. Materials that do not hold a charge are the good conductors, such as most metals.
4. Wool, glass, nylon, and silk are examples of materials that tend to become positively charged. Polystyrene, rubber, and plastics tend to become negatively charged.
5. A sample list, arranged from strongest tendency to be negatively charged to strongest tendency to be positively charged, might be ordered PVC, plastic wrap, plastic ruler, rubber, cotton, silk, wool, glass.

Conclude and Apply

1. There are positively charged particles in objects with a net negative charge and negatively charged particles in objects with a net positive charge. If an object or area of an object carries a net charge, it has more of one kind of charge than of the other. Neutral objects have equal numbers of positive and negative charges.
2. Even though air is a good insulator of electric charge, water vapor in the air can help pull electric charge off a material. Thus, materials in the lab lose their charge over time.
3. No. A conductor such as a metal rod will not hold a charge through the lab's procedures. Because a separation of charges can easily be induced in a neutral conductor, the metal rod will be attracted to any charged object, positive or negative.
4. When plastic wrap is pulled from its roll, the result is a charge imbalance that is similar to the situation when you pulled two strips of tape apart. This results in an attractive force between different parts of the plastic wrap.

Going Further

Students should know how to charge an electroscope. Once it has a known charge, they should describe the movement of the leaves that will be caused by objects with like charges compared to movements caused by objects with unlike charges.

Data Table

Material 1	Material 2	Charge on ruler (+, −, 0)	Observation of ruler's movements	Charge on material 1 (+, −, 0)	Charge on material 2 (+, −, 0)
wool	rubber	−	repulsed by rubber rod	+	−
plastic baggie	rubber	−	attracted to rubber	−	+
PVC	wool	−	repulsed by PVC	−	+

Real-World Physics

The strap or chain helps to drain excess charge that can build up while the truck tires roll along the road.

Chapter 20 Study Guide

Vocabulary Review

1. neutral
2. Coulomb's law
3. grounding
4. electrostatics
5. coulomb
6. charging by conduction
7. conductor
8. electroscope
9. insulators
10. charging by induction
11. elementary charge

Section 20-1 Electric Charge

1. a known
2. true
3. repel
4. protons
5. Benjamin Franklin
6. true
7. true
8. energy
9. true
10. electrons
11. −
12. +
13. −
14. +
15. The protons are positive and are located in the nucleus. The electrons are negative and surround the nucleus.
16. Electrons from one of the objects are transferred to the other. The object that lost electrons becomes positively charged and the object that gained electrons becomes negatively charged.
17. insulator
18. insulator
19. conductor
20. conductor
21. insulator
22. conductor
23. insulator
24. conductor
25. insulator
26. conductor
27. insulator
28. insulator
29. insulator
30. conductor
31. insulator
32. insulator
33. insulator
34. conductor
35. conductor

Section 20-2 Electric Force

1. The charges exert either an attractive or repulsive force that acts over a distance.
2. Metals are good conductors. The charges move quickly from the knob to cover the entire surface of the leaves, making their repulsion obvious.
3. **a.** The rod exerts an attractive force on the free electrons. The free electrons are drawn to the top of the sphere, producing a negative charge. Since the number of free electrons on the sphere is unchanged, the bottom of the sphere has a positive charge. This is called charging by induction.

   b. The sphere will have a net negative charge.

   c. The sphere will look like Figure C because it is left with the negative charges that it gained when it was grounded.

   d. The sphere will look like Figure A because the excess electrons will drain to the ground, and the sphere will become neutral.

   e. The sphere would have a positive charge.

4. b
5. a
6. c
7. b
8. d
9. b
10. $r = \sqrt{\dfrac{Kq_Aq_B}{F}}$

$= \sqrt{\dfrac{(9.0\times10^{9}\ \text{N·m}^2/\text{C}^2)(1.60\times10^{-19}\ \text{C})(1.60\times10^{-19}\ \text{C})}{2.00\ \text{N}}}$

$= 1.1\times10^{-14}$ m

11. Since the magnitude of the charge on an electron is equal to that on a proton, the distance is the same as in Question 10, $r = 1.1\times10^{-14}$ m.
12. $F = K\dfrac{q_Aq_B}{r^2} = (9.0\times10^{9}\ \text{N·m}^2/\text{C}^2)$

$\left(\dfrac{(1.60\times10^{-19}\ \text{C})(1.60\times10^{-19}\ \text{C})}{(2(1.1\times10^{-14}\ \text{m}))^2}\right)$

$= 0.48$ N

13. Possible answers include collecting soot in smokestacks, applying paint by induction, and deposition of toner in photocopy machines.
14. Water is a good conductor of electricity and even small amounts of water vapor in the atmosphere help conduct charge away from the surface of metal objects and to the ground. On dry days with little humidity in the air, the charge builds up until another grounded object releases the static electricity, such as your own body.

Section 20-1 Quiz

1. Electrostatic forces both attract and repel; gravitational forces only attract. Electrostatic forces can be stronger than gravitational forces in small objects. The charges that produce electrostatic forces dissipate over time; gravitational forces do not.
2. The driver transferred charges while sliding across the seat. When the metal door was touched, the imbalance was discharged.
3. The negative charge from the plastic transfers to the metal; because metal is a conductor, the charge spreads over the entire surface of the metal.
4. The end of the glass that was rubbed is positive, and the plastic is negative. The charged ends attract one another, so the suspended glass rod swings toward the ruler.
5. An atom is made up of a positively charged nucleus and negatively charged electrons. In a neutral atom, the positive charge of the nucleus exactly balances the negative charge of the electrons. To give the atom a positive charge, remove one or more electrons.

Section 20-2 Quiz

1. The electron attracts the proton with same amount of force, in accord with Newton's third law.
2. **a.** positive
   b. It decreases to one ninth of its original value.
   c. It decreases to one twenty-fifth of its original value.
3. He made them of the same material, made them the same size, and charged them while they were touching each other.
4. $F = K\dfrac{q_Aq_B}{r^2} = (9.0\times10^{9}\ \text{N·m}^2/\text{C}^2)$

$\left(\dfrac{(12\times10^{-9}\ \text{C})(15\times10^{-9}\ \text{C})}{(0.100\ \text{m})^2}\right)$

$= 1.6\times10^{-4}$ N

5. $q = r\sqrt{\dfrac{F}{K}} = (0.12\ \text{m})\sqrt{\dfrac{3.0\times10^{-5}\ \text{N}}{9.0\times10^{9}\ \text{N·m}^2/\text{C}^2}}$

$= 6.9\times10^{-9}$ C

Chapter 20 Reinforcement

Jumping Disks

1. The aluminum pieces separated from one another because they picked up the same charge from the plastic.
2. It was stronger because the aluminum remained held to the plastic even when it was vertical.

3. The aluminum pieces jumped off the surface of the plastic. Electrons were transferred by conduction until the aluminum had the same charge as the plastic and the aluminum pieces repelled one another.

Chapter 20 Enrichment

Static Electricity

1. The polystyrene alternately sticks to the tube and is repelled by the tube. This happens because the tube gains electrons as it is handled. The electrons create a negative charge on the tube, and this in turn induces a positive charge on the polystyrene. The positive charge on the polystyrene causes the polystyrene to stick to the tube. When this happens, the polystyrene picks up electrons and becomes negatively charged, and this causes the tube to repel the polystyrene.
2. When the tube is rubbed with the wool cloth, electrons are transferred to the tube, which makes it more negatively charged than it was before.
3. The polystyrene alternately clung to the tube and was repelled by the tube. The polystyrene clung to the tube when the negative charge from the wool induced a positive charge in the polystyrene. The polystyrene was repelled by the tube when the polystyrene gained electrons from the tube.
4. When you move your fingers along the outside of the tube, the polystyrene is repelled by your fingers. The negative charge on the tube induces a positive charge on your fingers. The positive charge on your fingers repels the positively charged polystyrene so the polystyrene moves away from your fingers as they move along the outside of the tube.
5. You cannot effectively charge a metal tube while holding it in your bare hand because the metal is a conductor, and any charge you add to the tube will quickly flow into your body. Therefore, you would not expect the polystyrene pieces to pick up an induced charge, and you would not see the attractions and repulsions you see with the plastic tube.
6. Metal, because the charge would spread over the surface of the dome and not affect the campers inside.

Transparency 20-1 Worksheet

Rule of Electric Charges

1. two: positive and negative
2. Like charges repel each other; unlike charges attract each other.
3. The two pith balls would be attracted to the negatively charged object because unlike charges attract each other.
4. The two pith balls would move even farther apart because like charges repel each other.
5. Nothing. There is no like or opposite charge with which to react.
6. Charges come from atoms. Matter normally is neutral because there are equal numbers of electrons and protons. If atoms from one object lose electrons to another object, the first object has an excess of protons and is positively charged. The other object has an excess of electrons and is negatively charged.
7. The rubber rods would repel each other because they have the same charge. The wool would attract either of the two rubber rods because the wool and the rubber rod would have opposite charges.
8. They eventually will fall because the negatively charged charged balls will bleed electrons into the air and become neutral. The positively charged balls will pick up electrons from the air and become neutral. All the balls eventually will have no net charge (equal charges).

Transparency 20-2 Worksheet

Determination of Charge

1. They must be good conductors of electricity, generally metal.
2. The thin metal is light, so the force of the charges can easily overcome the force of gravity to lift the leaves away from one another.
3. The leaves would move away from one another because the charge would pass to the knob and the leaves. They would become negative and repel one another.
4. The electroscope was already negatively charged, so the leaves repelled one another. When a negatively charged object touches the knob, more electrons transfer to the electroscope and onto the leaves. The force of repulsion increases, so the leaves move farther apart.
5. The electroscope was negatively charged. When the positively charged object is touched to the knob, electrons transfer from the electroscope to the positively charged object. This reduces the charge on the leaves and they fall.
6. You would assume that the rod was uncharged because it had no effect on the charge of the electroscope.
7. Touch the rod to the knob of the electroscope. If nothing happens, the rod is uncharged. If the leaves fall, the rod is negatively charged. If the leaves repel even more, the rod is positively charged.

Transparency 20-3 Worksheet

Charging by Induction

1. The stands must be insulators to prevent the charges from transferring away from the spheres.
2. The negative charges on the rod repel the negative charges on the sphere, and some of them move to the right sphere.
3. The excess negative charges on the right sphere would transfer back to the left sphere, and both spheres would be neutral again.
4. If the spheres are separated before the rod is removed, they remain charged. The charges distribute themselves over the surface of each sphere.
5. Nothing. It remains negatively charged because no electrons are transferred to the spheres.
6. Bring the rod near one side of the sphere. Electrons on that side of the sphere are repelled to the other side. Touch the other side with your finger. The excess electrons transfer to your finger and into the ground. Then remove the rod. The sphere is left positively charged.
7. The positively charged rod would draw electrons on the left sphere toward it. This would leave the right side of the left sphere with an excess of positive charges and the electrons from the right sphere would move toward it, leaving the right sphere with an excess of positives. If the spheres are separated and then the rod is removed, both spheres would be charged, but the charges would be opposite those shown in the pair of spheres on the right.

Transparency 20-4 Worksheet

Electric Discharge

1. There is no net charge because the electrons and positive ions are evenly distributed.
2. The positive charges collect near the top of the cloud, and the negative charges collect near the bottom.
3. The negative charges at the bottom of the cloud repel the negative charges in the tree and ground, leaving the surface with a net positive charge.
4. Negative charges in one part of the cloud might discharge toward positive regions of the same cloud. The overall charge of the cloud would remain the same because no charges were transferred to or away from it.

5. Negative charges build up in one area of a cloud and discharge to the positive area of another cloud. The cloud from which the negative charges came is left with a net positive charge. The cloud to which the negative charges jumped would have a net negative charge.
6. When the lightning strikes the tree the first time, it gives the tree an excess of negative charge. Until that charge can be dissipated, and/or induction from the cloud could again give the tree a positive charge, it is unlikely that a discharge would be attracted to it.
7. Lightning rods don't attract lightning. The lightning rod has a wire running into a plate in the ground. Because it's the highest point, it is likely that the lightning discharge will strike it before striking the building. It provides an easy path for the discharge to be transferred into the ground rather than randomly striking something that could easily be damaged by the heat or forcing the discharge to jump from on object to the other on its way to the ground.
8. A lightning discharge is orders of magntitude larger than the tiny discharge you feel. However, they are produced in the same way. When you walk across the rug, you pick up negative charge, which moves over the surface of your body. When you bring a finger near a metal object, the negative charge in your finger induces a positive charge in the other object and a discharge occurs.

Chapter 20 Assessment

Understanding Physics Concepts

1. b
2. a
3. c
4. b
5. d
6. a
7. d
8. b
9. c
10. b
11. a
12. d
13. b
14. c
15. a

Thinking Critically

1. $F = K\frac{qq}{r^2} = 64\text{ N}$

   $K\left(\frac{(2q)(2q)}{(2r)^2}\right) = K\left(\frac{4q^2}{4r^2}\right) = K\frac{qq}{r^2} = 64\text{ N}$
2. Bring an object of known charge near the object, and see whether the object of known charge is repelled or attracted.
3. The charged comb or rod induces a separation of charge in the paper, which is then attracted to the charged object.
4. $F = K\frac{q_Aq_B}{r^2} = (9.0\times10^9\text{ N·m}^2/\text{C}^2)$

   $\left(\frac{(1.8\times10^{-6}\text{ C})(1.0\times10^{-6}\text{ C})}{(0.014\text{ m})^2}\right) = 83\text{ N}$
5. The diagram should show a cloud with more negative charges near the bottom, and more positive charges near the top. The diagram should also show the ground with more negative charges near the surface. The explanation should mention processes in the cloud that result in the separation of charges. The negative charges at the bottom of the cloud then induce a positive charge in the ground. The air between becomes a plasma that conducts the charges from the cloud to the ground.
6. The negative charges in one cloud interact with the positively charged area of another cloud.
7. **a.** attractive

   b. $F = K\frac{q_Aq_B}{r^2} = (9.0\times10^9\text{ N·m}^2/\text{C}^2)$

   $\left(\frac{((1.0\times10^{12}\text{ electrons})(1\text{ C}/6.24\times10^{18}\text{ electrons}))^2}{(0.100\text{ m})^2}\right)$

   $= 2.3\times10^{-2}\text{ N}$

8. While rubber is generally an insulator, rubber infused with carbon makes a conductive material. This combination allows the tires to be grounded and conduct static electricity away from the car's metal surfaces as you drive. If tires were made of pure rubber, the electrical charge would build on the outside of the car and shock you as you exited the vehicle.
9. **a.** The charge on the rod must be the same as the charge on the leaves of the electroscope.
   b. The electroscope was negatively charged. Wool rubbed on plastic has a positive charge and would attract the negative charge from the electroscope, collapsing the leaves.
10. The kettle of water adds humidity to the air. This reduces the chance of getting shocked when walking across rugs.

Applying Physics Knowledge

1. **a.** The screen is negatively charged, even after it is turned off. Positive particles of dust in the air are attracted to the screen and stick to it.
   b. No. First of all, the negative charge on the screen is being continually replaced. This makes it very difficult to remove the dust because it is strongly attracted to the screen. Secondly, the screen can induce a positive charge in the dust rag, which can produce a large spark.
2. $q_B = \dfrac{Fr^2}{Kq_A}$

   $= \dfrac{(65\ \text{N})(0.050\ \text{m})^2}{(9.0\times10^9\ \text{N·m}^2/\text{C}^2)(6.0\times10^{-6}\ \text{C})}$

   $= 3.0\times10^{-6}\ \text{C}$
3. **a.** $F = ma = (1.67\times10^{-27}\ \text{kg})(9.80\ \text{m/s}^2) = 1.64\times10^{-26}\ \text{N}$

   b. $r = \dfrac{Kq_Aq_B}{F}$

   $= \sqrt{\dfrac{(9.0\times10^9\ \text{N·m}^2/\text{C}^2)(1.60\times10^{-19}\ \text{C})(1.60\times10^{-19}\ \text{C})}{1.64\times10^{-26}\ \text{N}}}$

   $= 0.12\ \text{m}$
4. **a.** $F_A = K\dfrac{q_Aq_B}{r^2} = (9.0\times10^9\ \text{N·m}^2/\text{C}^2)\left(\dfrac{(2.2\times10^{-6}\ \text{C})(4.5\times10^{-7}\ \text{C})}{(0.020\ \text{m})^2}\right)$

   $= 22\ \text{N}$

   $F_C = K\dfrac{q_Bq_C}{r^2} = (9.0\times10^9\ \text{N·m}^2/\text{C}^2)\left(\dfrac{(4.5\times10^{-7}\ \text{C})(9.0\times10^{-5}\ \text{C})}{(0.12\ \text{m})^2}\right)$

   $= 25\ \text{N}$

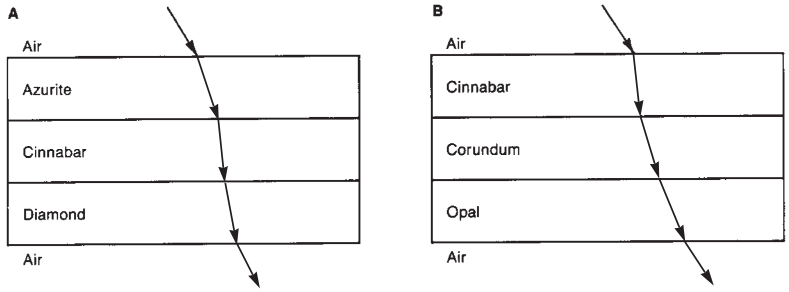
   b. $F_{net} = F_A - F_C = 22\ \text{N} - 25\ \text{N} = -3\ \text{N}$, or 3 N acting to the left

Art for Answer Key section

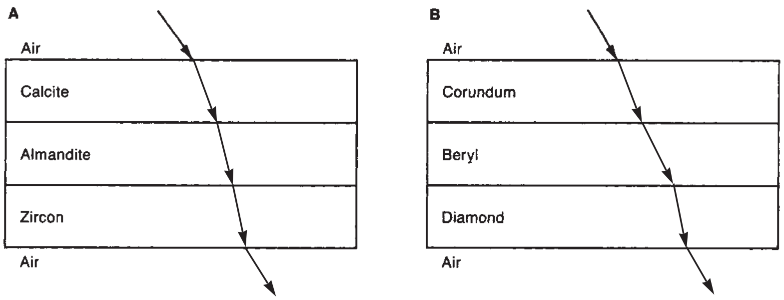
[crf_ch16_ta04] Enrichment Question #2--guide

Art for Answer Key section

[crf_ch18_ta04] Enrichment Table--guide



[crf_ch18_ta06] Enrichment Question #4--guide



Art for Answer Key section

Enrichment Question #8--guide

Set up experiment like that in the figure

↓

Shine light through the slits

↓

Measure d, L, and x.

↓

Substitute these values into the equation $\lambda = \frac{xd}{L}$

↓

Solve for λ